AFWAL-TR-88-3101

Automated Structural Optimization System (ASTROS) User Training Workshop

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Flight Dynamics Laboratory
Wright Research and Development Center
Air Force Systems Command
Wright-Patterson AFB, OH 45433-6523

NOTICE

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The ASTROS (Automated Strucutral Optimization System) procedure provides multidisciplinary analysis and design capability for aerospace structures. The engineering analysis capabilities in the system include structural analysis (static and dynamic), aeroelastic analysis (static and dynamic) and automated design. A specifically designed data base and executive system were implemented to maximize the system's efficiency, flexibility, and maintainabilit The charts used in the ASTROS User Training Workshop, conducted by the Air Force and Northro are presented in this report.

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FOREWORD

Contract F33615-83-C-3232, entitled "Automated Strength-Aeroelastic Design of Aerospace Structures," was initiated by the Analysis and Optimization Branch (FDSR) of the Air Force Wright Aeronautical Laboratories. The objective of this contract was to develop a computer procedure which can assist significantly in the preliminary automated design of aerospace structures. This report consists of materials used at the ASTROS User Workshop.

Northrop Corporation, Aircraft Division, was the primary contractor for this program with Universal Analytics, Inc. (UAI) and Kaman AviDyne acting as subcontractors. The principal contributors to this report were: E. H. Johnson, the overall Program Manager at Northrop D. J. Neill, Project Co-Principal investigator, D. L. Herendeen, the Project Manager at UAI, and R. A. Canfield, the Air Force Project Engineer.

Capt R. A. Canfield was the Air Force Project Manager while Dr V. B. Venkayya initiated the program at the Air Force and provided overall program direction. The work reported on in this report was performed from 01 July 1983 through 24 June 1988.

The authors would like to acknowledge those who acted as instructors at the ASTROS User Training Workshop held at Wright-Patterson AFB from 20 June to 24 June, 1988:

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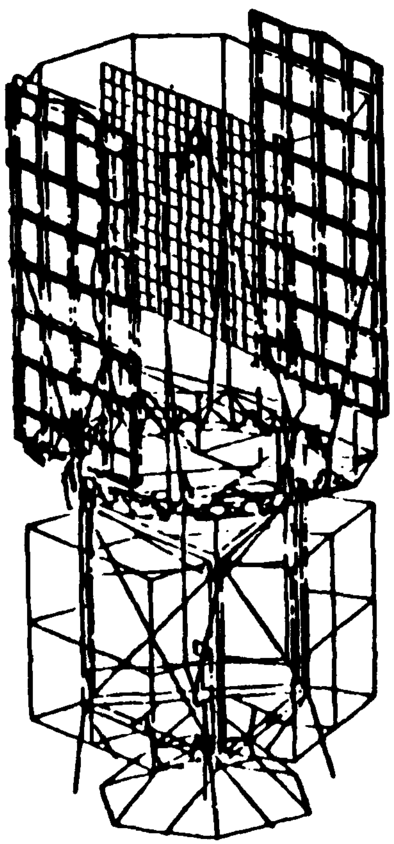
Mr Les Whitford	ASD Computer Center

TABLE OF CONTENTS

ASTROS User Training Workshop

20–24 June 1988



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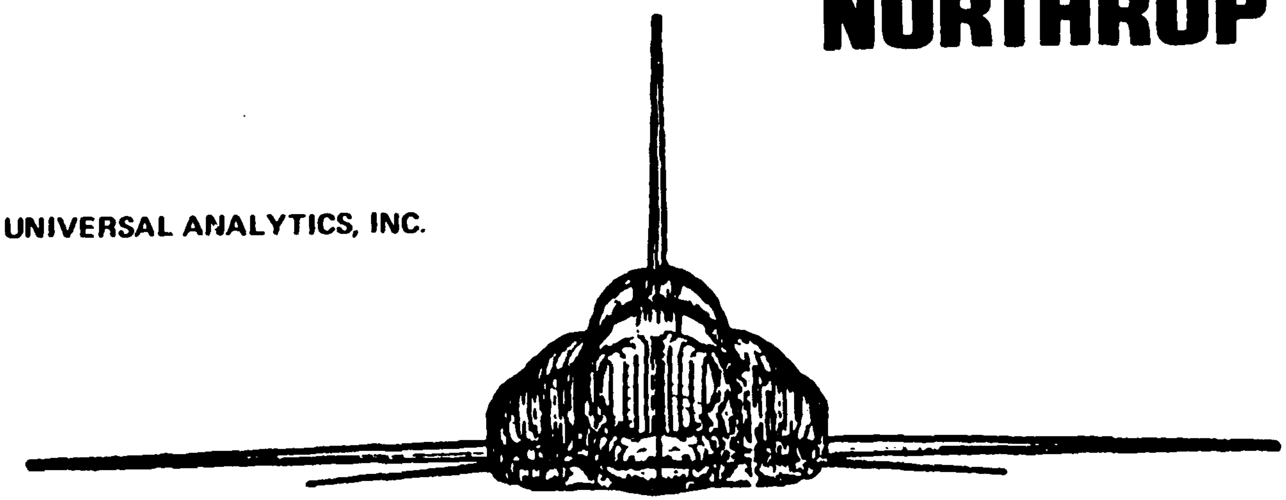

Overview

AUTOMATED STRENGTH – AEROELASTIC DESIGN OF AEROSPACE STRUCTURES

CONTRACT NUMBER:	F33615-83-C-3232
SPONSOR:	AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
PROJECT ENGINEER:	CAPT. R. CANFIELD
CONTRACTOR:	NORTHROP CORPORATION, AIRCRAFT DIVISION
SUBCONTRACTORS:	UNIVERSAL ANALYTICS, INC. KAMAN AVIDYNE
PERFORMANCE PERIOD:	JULY 1983 – JULY 1988

85-50003
3K, 10A

OBJECTIVES AND PAYOFFS

OBJECTIVES

- AN AUTOMATED TOOL FOR PRELIMINARY STRUCTURAL DESIGN
- EMPHASIZE INTERDISCIPLINARY FEATURES OF THE DESIGN TASK
- PROVIDE A NATIONAL RESOURCE

PAYOFFS

- IMPROVED COMMUNICATION AMONG DESIGN TEAM MEMBERS
- IMPROVED DESIGN
- REDUCED DESIGN TIME

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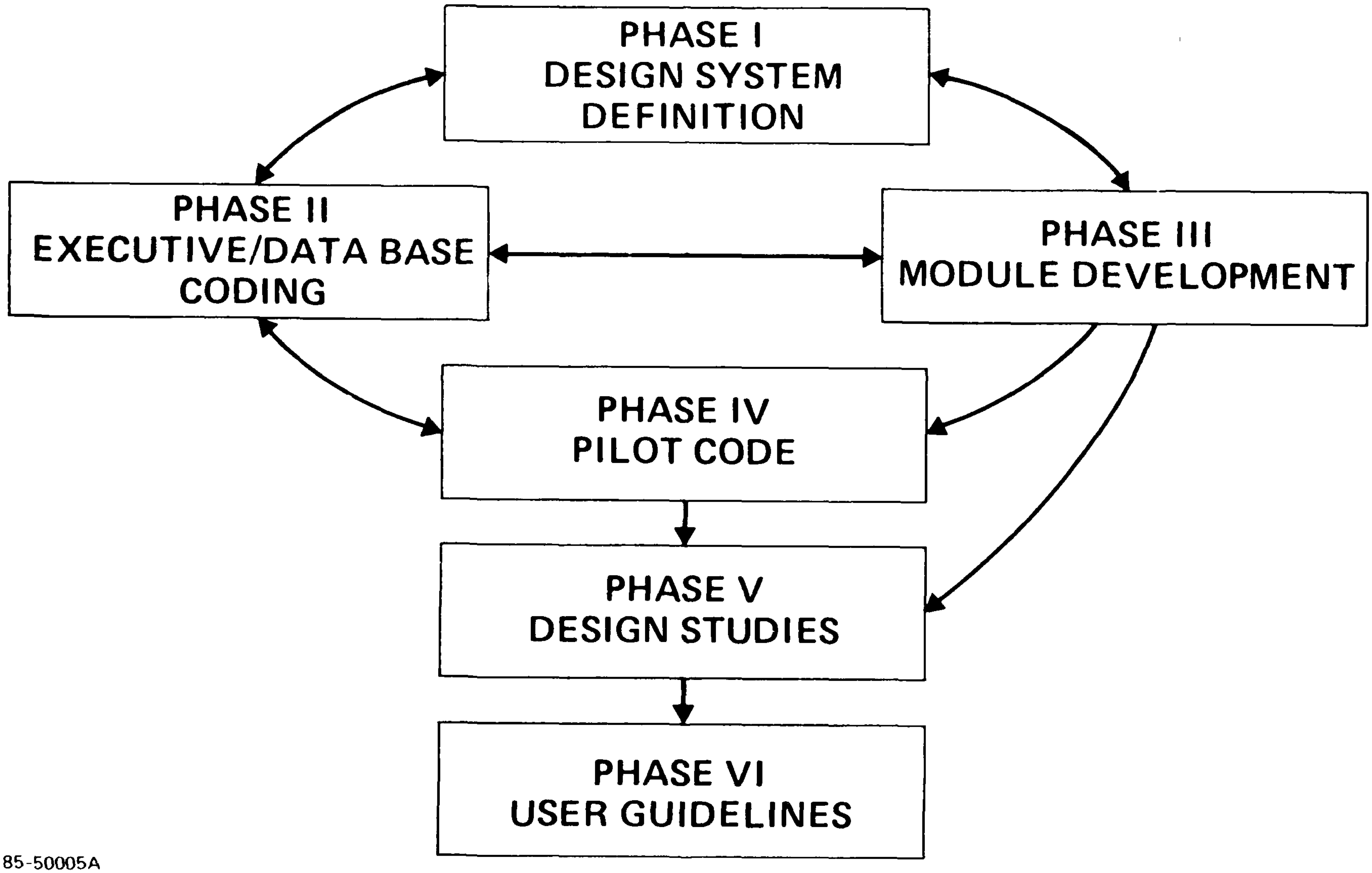
5B

ASTROS PHASES



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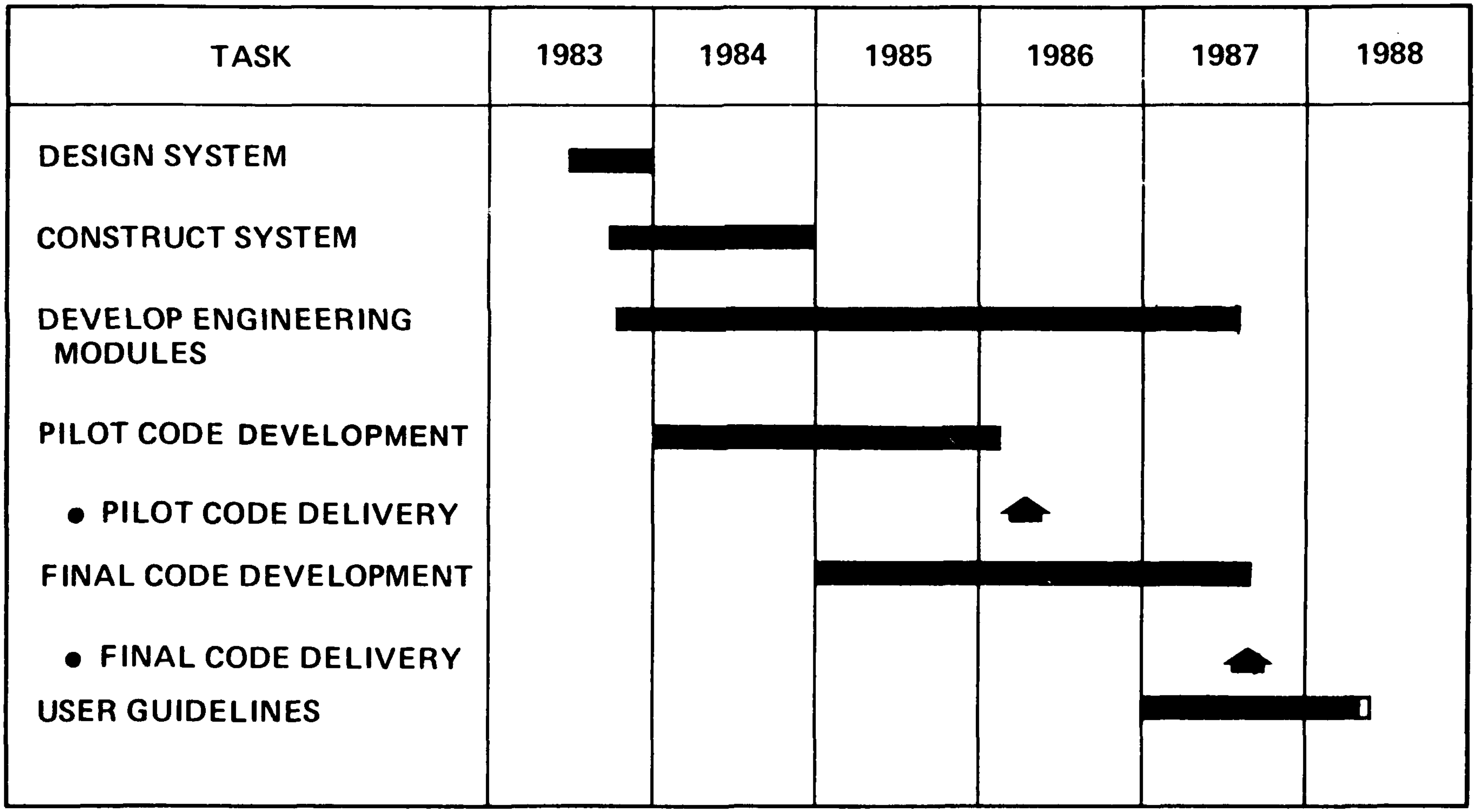
KEY ASTROS MILESTONES



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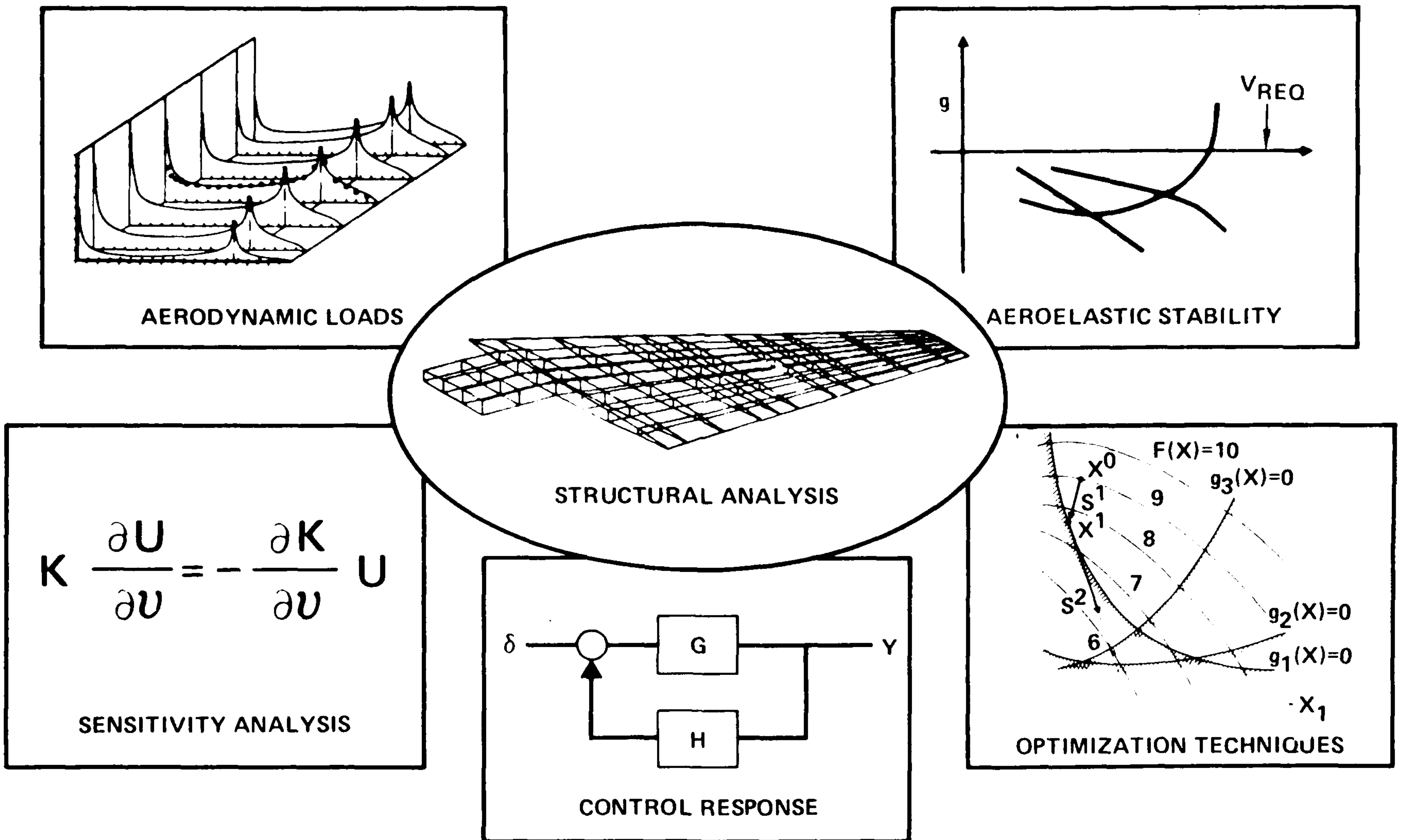
ENGINEERING DISCIPLINES



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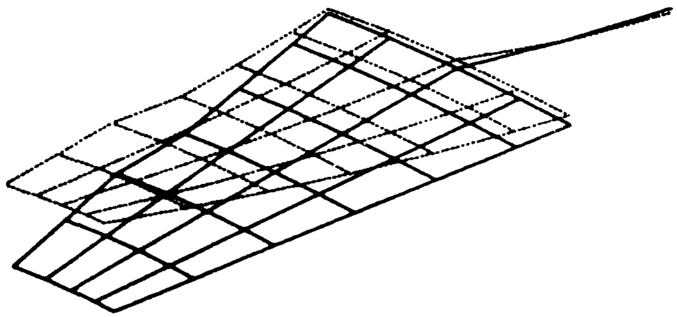
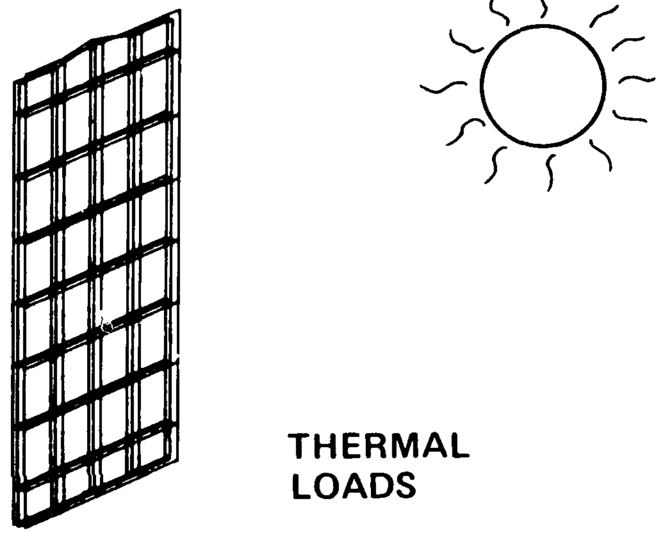
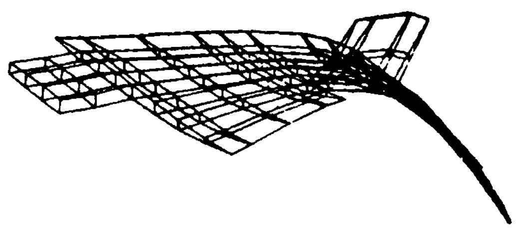
STRUCTURAL ANALYSES



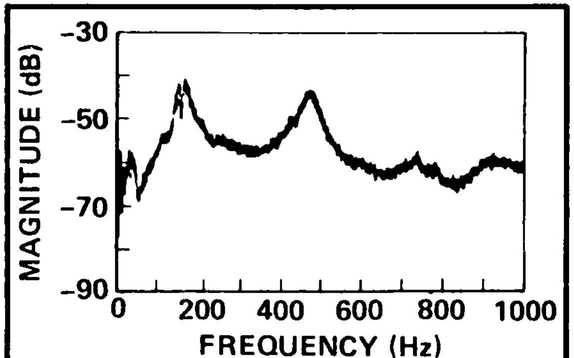
STATIC ANALYSIS



THERMAL
LOADS



EIGENVALUE ANALYSIS



DYNAMIC ANALYSIS

Software Resources for ASTROS

Structural Analysis	— NASTRAN
Static Aerodynamic Loads	— USSAERO
Unsteady Aerodynamic Loads	— Doublet Lattice CPM
Optimization Algorithms	— MDOT

DESIGN PARAMETERS

DESIGN VARIABLES

- ROD AREAS
- SHEAR ELEMENT THICKNESSES
- MEMBRANE ELEMENT THICKNESSES
- BARS
- CONCENTRATED MASSES

CONSTRAINTS

- STRESS-STRAIN
- DISPLACEMENT
- MODAL FREQUENCY
- AEROELASTIC EFFECTS
  - LIFT EFFECTIVENESS
  - AILERON EFFECTIVENESS
  - DIVERGENCE SPEED
- FLUTTER RESPONSE

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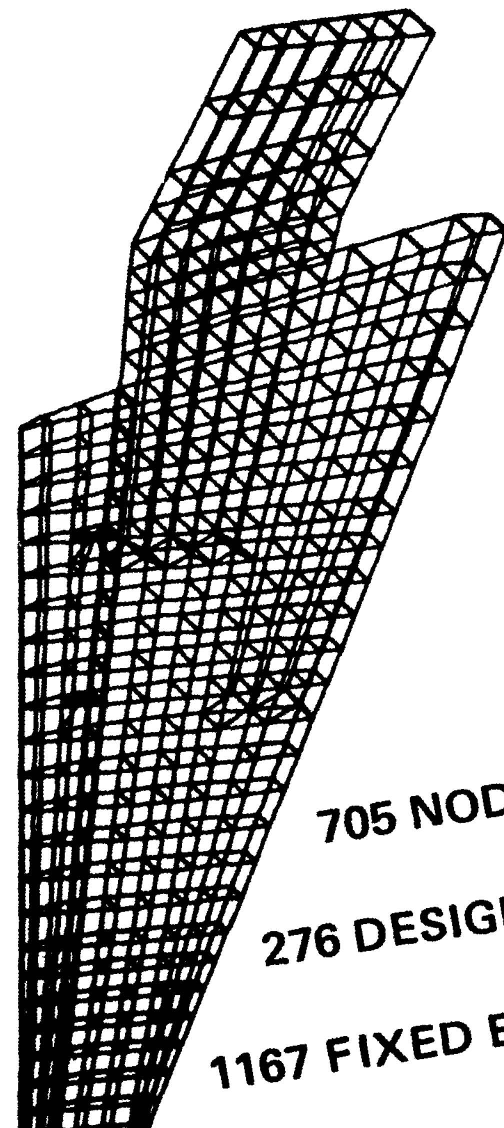
AN ARCHETYPICAL ASTROS APPLICATION



705 NODES

276 DESIGNED ELEMENTS

1167 FIXED ELEMENTS

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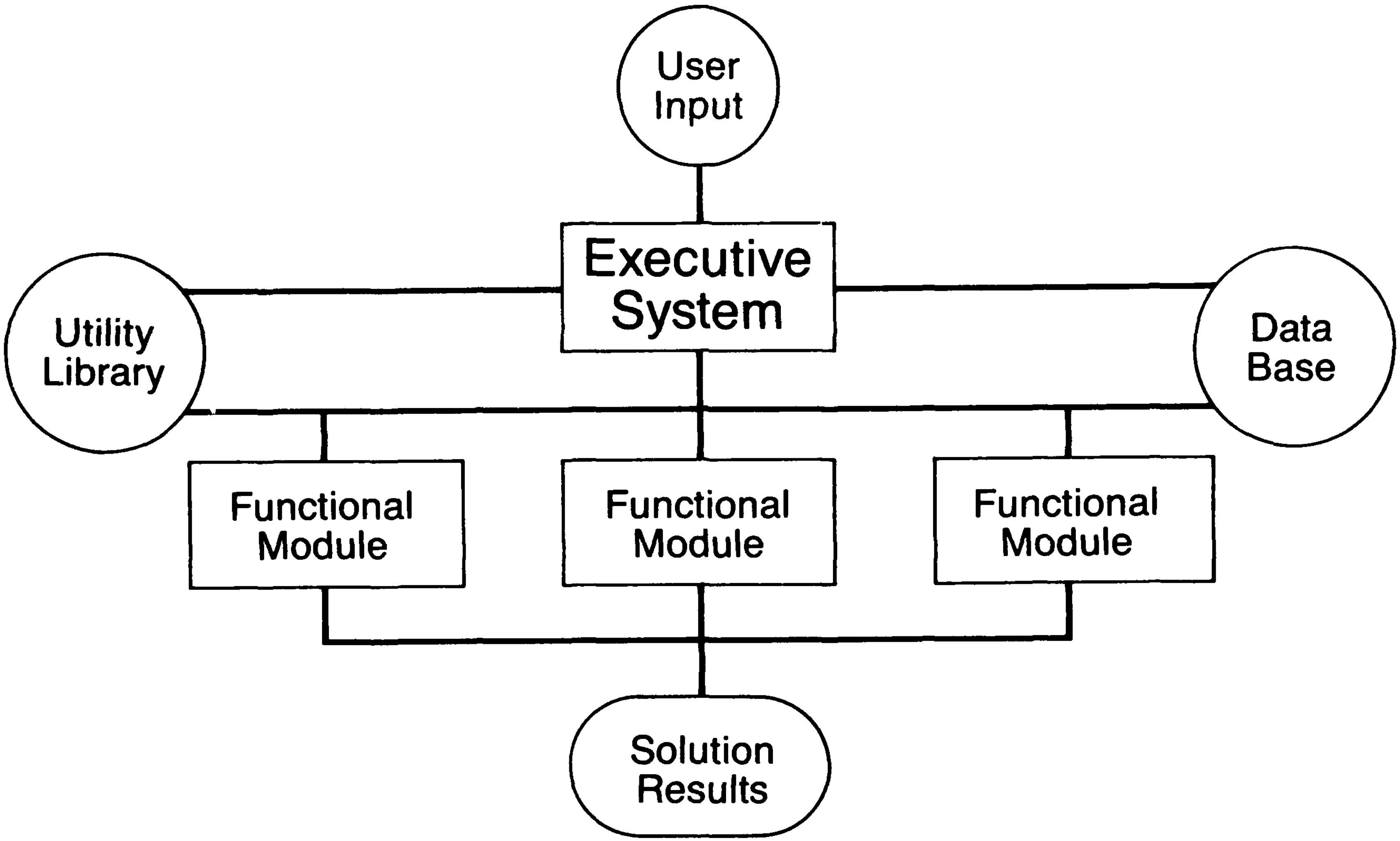
GIVEN:
- STRUCTURAL CONFIGURATION
- MATERIAL PROPERTIES
- DESIGN FLIGHT CONDITIONS
- DESIGN ALLOWABLES

DETERMINE
- THICKNESSES OF DESIGNED ELEMENTS
- OPTIONALLY — MASS BALANCE VALUES

POSSIBLE DESIGN CONSIDERATIONS
- MULTIPLE BOUNDARY CONDITIONS
- MULTIPLE FLIGHT CONDITIONS
- MULTIPLE STORE LOADINGS

ASTROS Architecture



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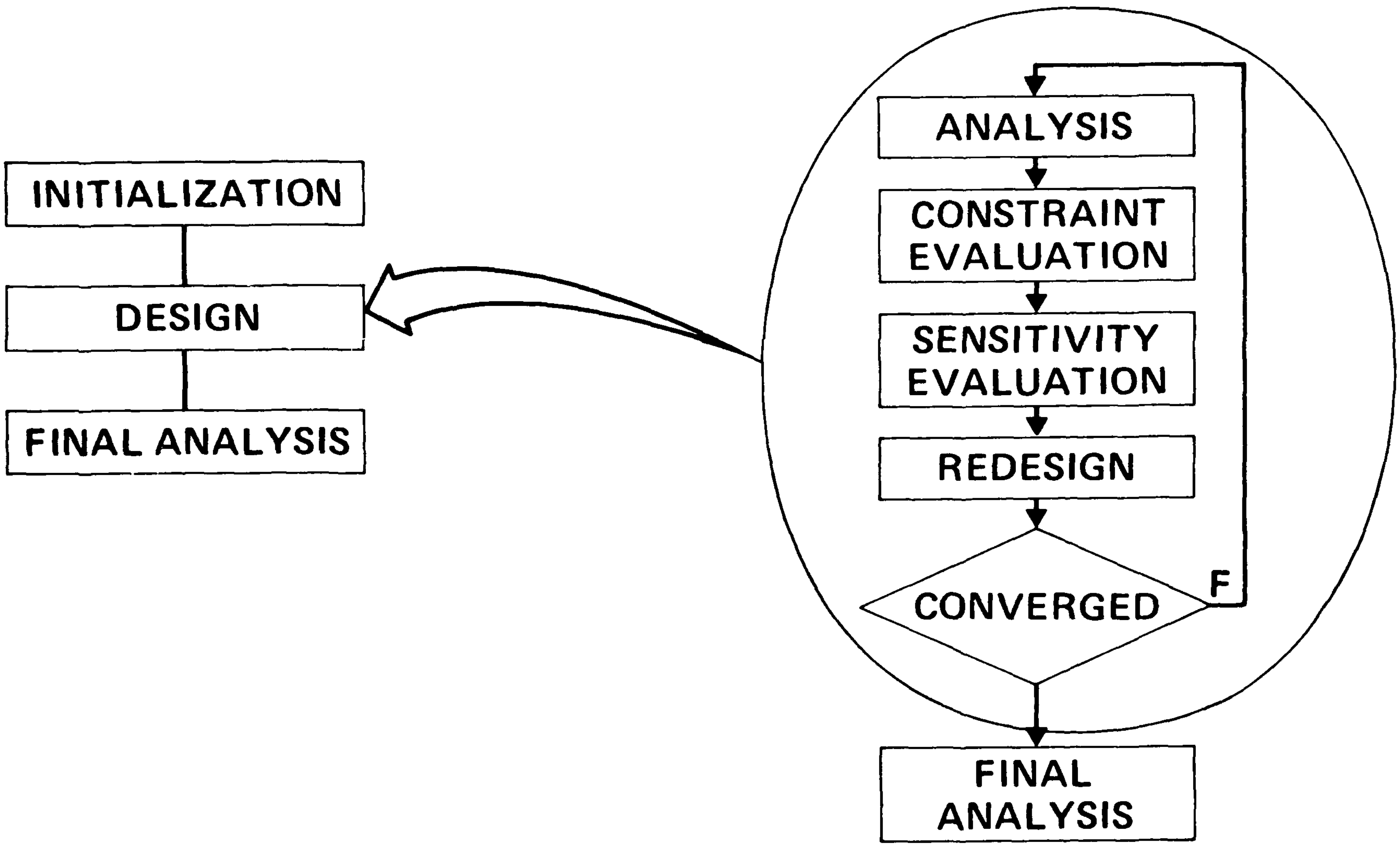
BASIC ASTROS SEGMENTS



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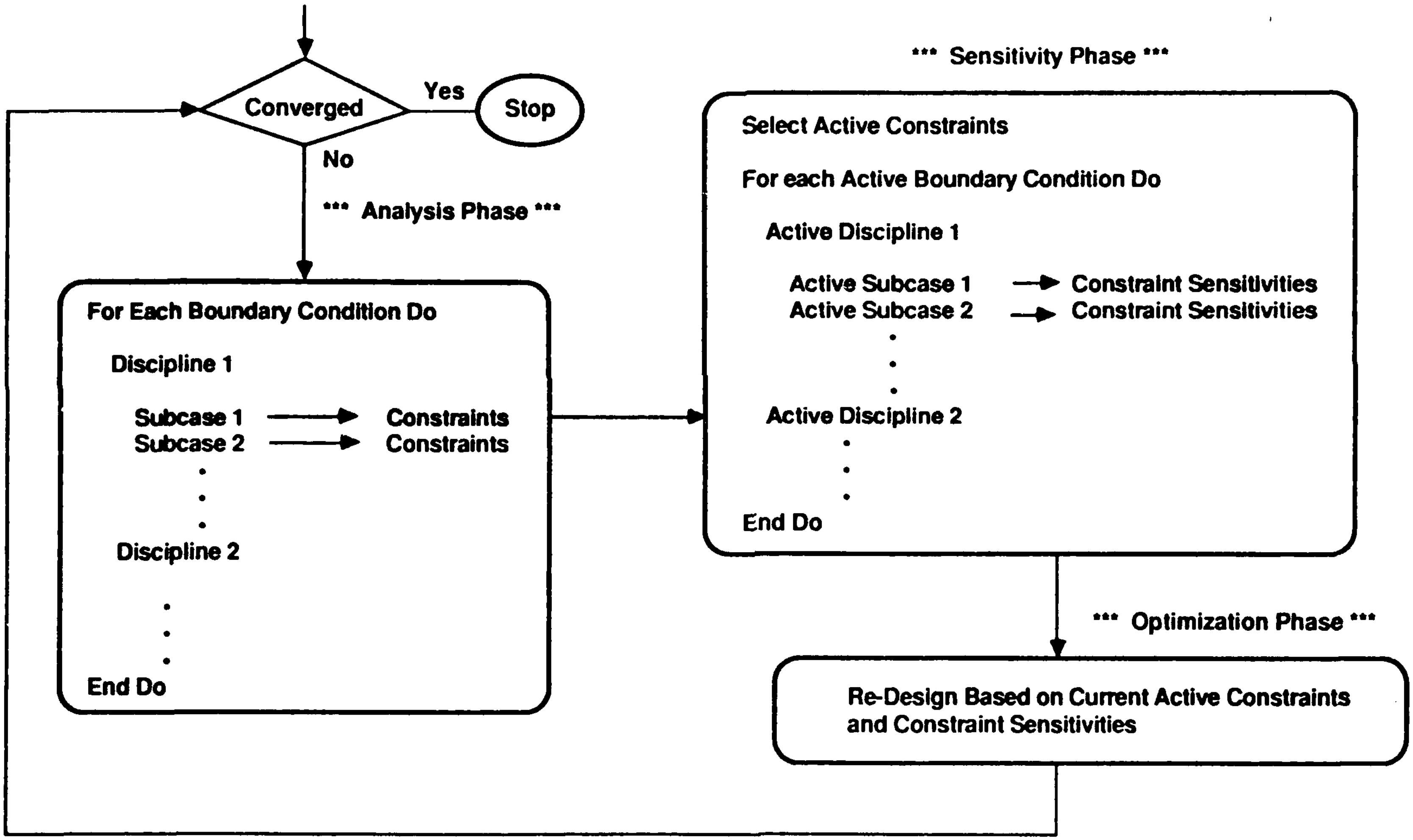
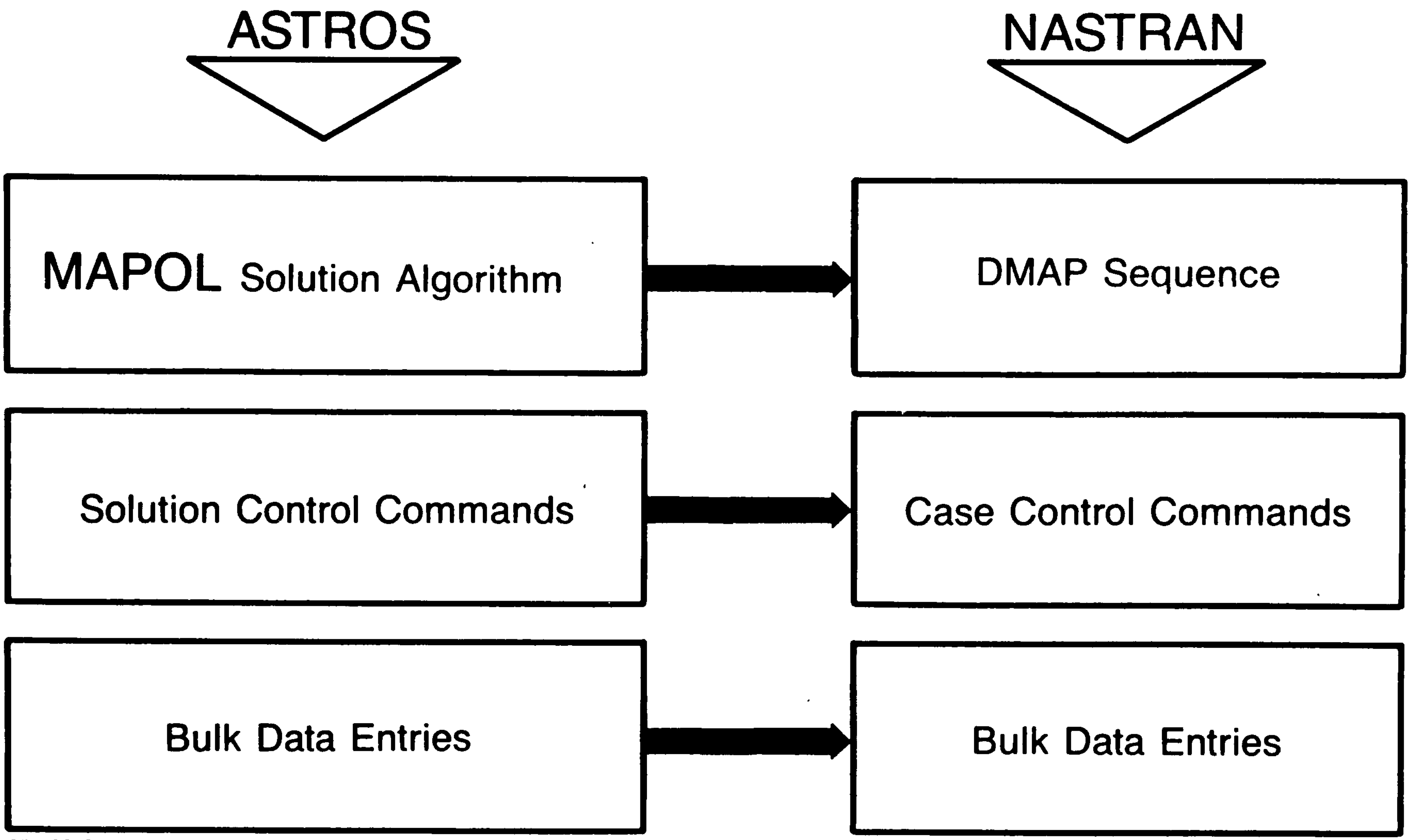
Multidisciplinary Optimization



User Input Data Stream



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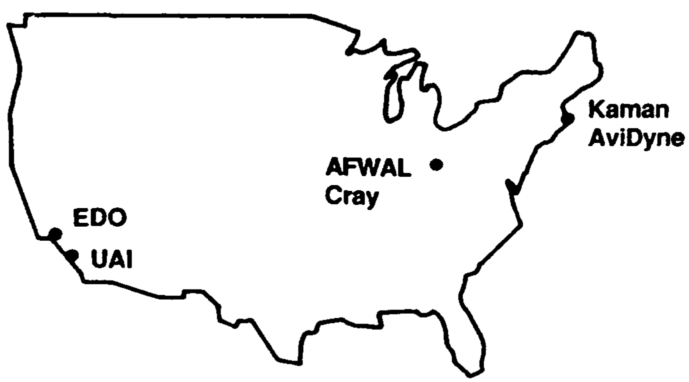
Astros Integration/Development Environment

The NORTHROP MicroVAX is the Central ASTROS Processor



Comunication with Central Processor		
Entity	**From**	**To**
AFWAL	Floppy	Floppy + CT + MT
UAI	Direct Line (IBM)	Direct Line (IBM)
Kaman AviDyne	Floppy	Floppy + MT
EDO	Floppy + MT	N/A
Astros + LV	Direct Line (VAX)	Direct Line (VAX)
Astros (IBM)	Floppy + MT=> CT	Floppy + CT => MT
Cray	N/A	? (AFWAL)

Ten Engineering Contributions of ASTROS

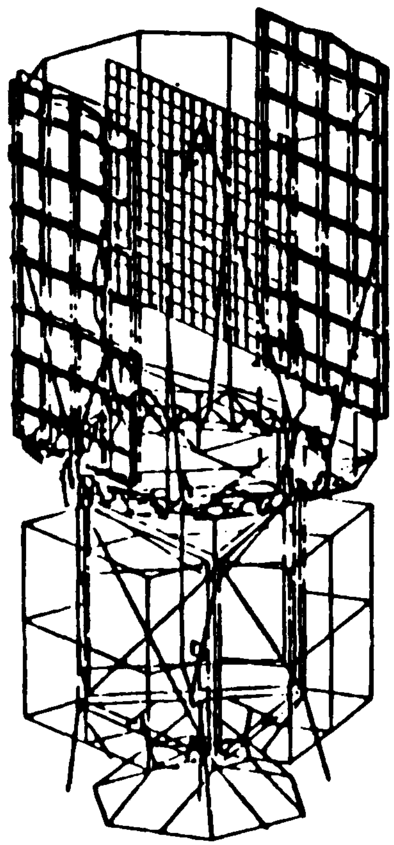
- Multidisciplinary Analysis and Design
- Analytical Sensitivity Analysis
- Approximation Concepts in a Production Code
- QUAD4 Element in the Public Domain
- Improved Supersonic Unsteady Aerodynamics
- Innovative Flutter Design Technique
- Nuclear Blast Analysis with Finite Elements and Advanced Aerodynamics
- Advanced Methods of Dynamic Reduction
- Design Variable Linking
- Aerodynamic Influence Coefficients For Static Aeroelasticity

Ten Software Contributions of ASTROS

- Framework For Multidisciplinary Analysis and Design
- Engineering Data Base
- High Level Executive System
- Obsolescence of Rigid Formats
- Unlimited Problem Size
- Explcitation of Microcomputers
- Built in Maintenance Features
- Improved Special Purpose Utilities
- Balanced Approach to Software Design
- Integration of Dispersed Development Team

ASTROS User Training Workshop

20–24 June 1988



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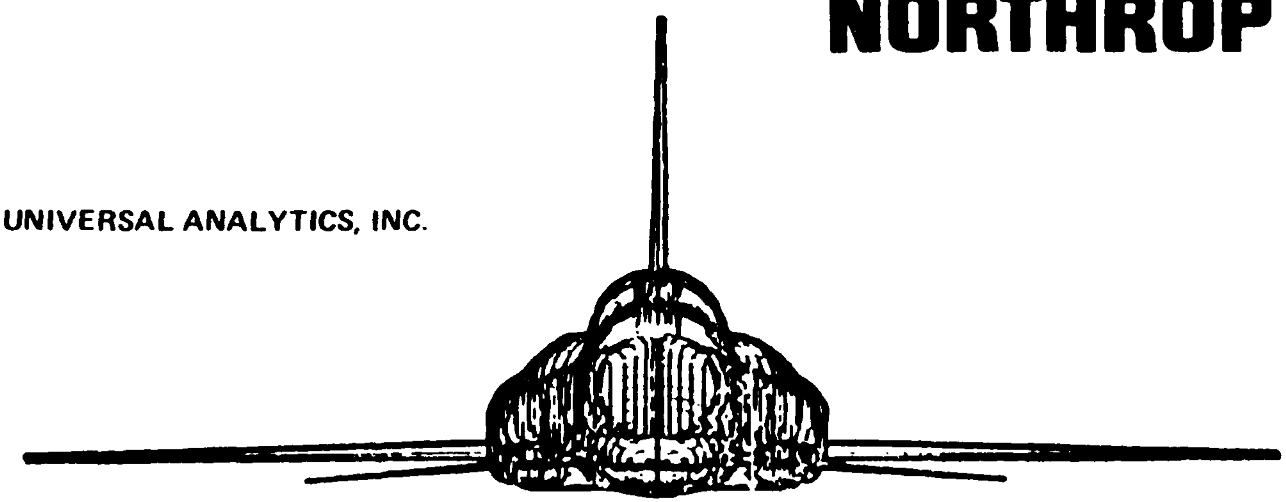


Theory

Agenda For Theoretical Discussion

- Introduction / Background
- Multidisciplinary Analysis and Design Concepts
- Finite Elements
- Static / Normal Modes Analyses
- Aerodynamic Analyses
- Automated Design
- Miscellaneous Analyses

Background - TSO

- **Developed By General Dynamics for the AFFDL**
- **Applies Rayleigh Ritz Analysis to a Trapezoidal Plate Model**
- **Includes in Design**
  - Strength
  - Flutter
  - Frequency
  - Lift Effectiveness
  - Control Effectiveness
- **Additional Analyses Available in Final Analysis**
  - Plots of Thicknesses and Response
  - Drag Polars
  - Detailed Analyses

Background - TSO

- **Strengths**

  Has a Extremely Efficient Analysis Procedure at Its Core

  Provides Basic Multidisciplinary Design

- **Weaknesses**

  Structural Analysis Simplistic

  Single Boundary Condition

  Only Three Composite Layers

- **Impact on ASTROS Significant**

Background - FASTOP

- **Developed for the AFFDL By Grumman**
- **Uses Finite Element Methods for the Structural Analysis**
- **Performs Strength / Flutter Design in Sequential Stages**
  - Fully Stressed Design Criteria Used for Strength
  - Flutter Sensitivity Criteria Used for Flutter
- **Strengths**
  - Detailed Structural Analysis
  - Efficient Resizing Algorithm
- **Weaknesses**
  - Sequential Design Not Necessarily Optimal
  - Limited Capability

Background - Further Motivation For a New Procedure

- Improved Optimization Techniques
- New Software Concepts
- Data Base Concepts
- FORTRAN 77
- New Computer Hardware

Promotes Maintenance and Enhancement

ASTROS Documentation

- **Theoretical Manual**

  Describes ASTROS Methods
  Emphasizes Innovative Features

- **User's Manual**

  Input and Output Description
  Techniques to Obtain Additional Output
  Creation and Modification of MAPOL Sequences

- **Application Manual**

  Documentation Resources
  Modeling Guidelines
  Sample Cases

- **Programer's Manual**

  Code Installation
  Module Description
  Data Base Calls
  Utility Calls

The Design Task

Minimize an Objective

$$F(v)$$

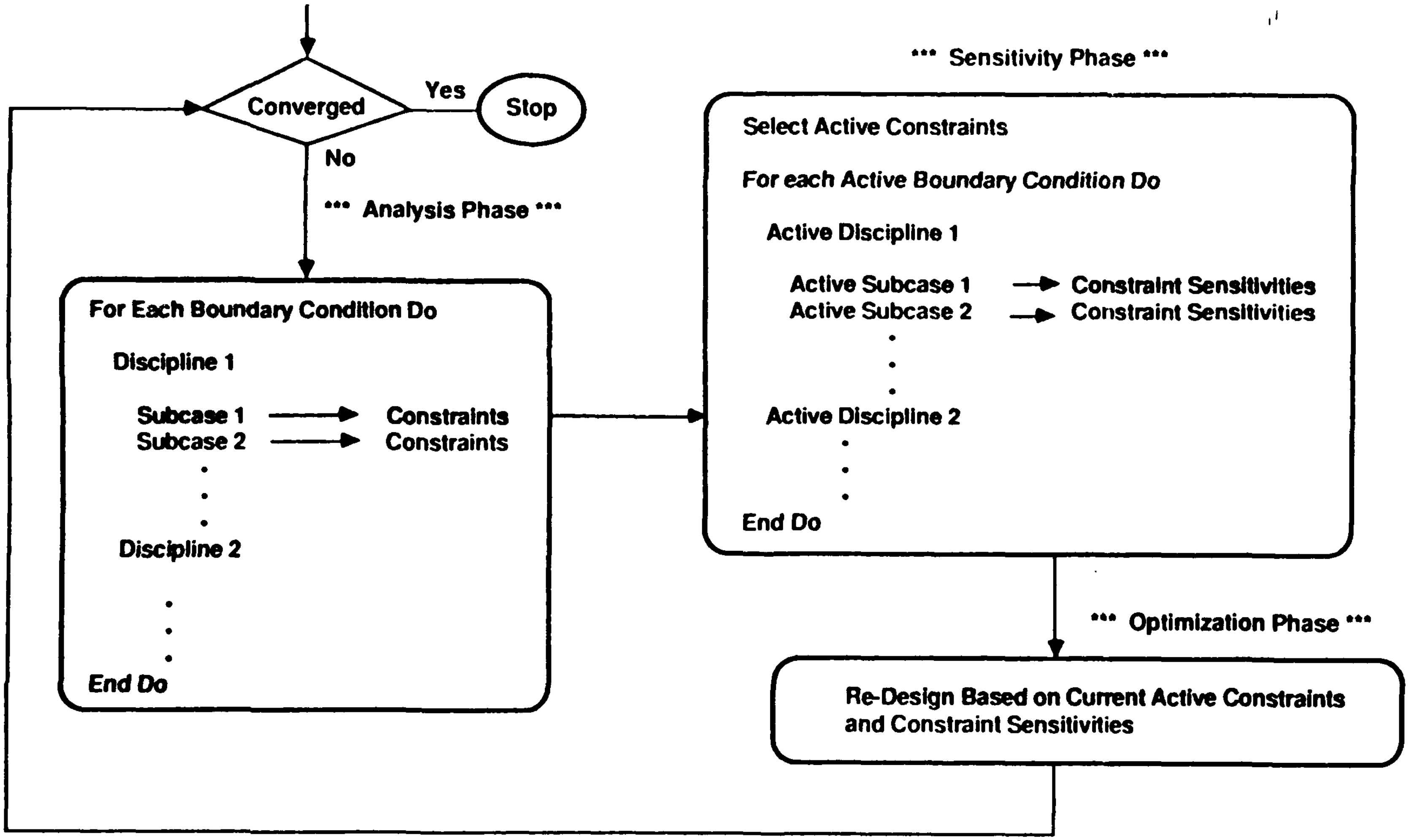
Subject to Constraints

$$g_j(v) \leq 0 \qquad j = 1, \text{ncon}$$

$$v_i^{lower} \leq v_i \leq v_i^{upper} \qquad n = 1, \text{ndv}$$

In ASTROS, the Objective is Always Weight

Multidisciplinary Optimization



Physical Design Variables

ELEMENT	DESIGN VARIABLE
CROD	Area
CSHEAR	Thickness
CQDMEM	Thickness (es)
CTRMEM	Thickness (es)
CQUAD4	Membrane Thickness (es)
CBAR	Area
CONM2	Mass
CELAS1 , 2	Stiffness
CMASS1 , 2	Mass

Physical Design Variables

- Mass and Stiffness Matrices are a Linear Function of the Design Variable

- Bar Element an Exception

$$I_1 = R_1 A^{\alpha}$$
$$I_2 = R_2 A^{\alpha}$$

- Bending Effects are Ignored for Two-Dimensional Elements

- Each Ply Direction Can Be a Separate Local Variable

Design Variable Linking Options

$$\underset{\text{Local Variables}}{\{\, t \,\}} = \underset{\text{Linking Matrix}}{[\, P \,]} \; \underset{\text{Global Variables}}{\{\, v \,\}}$$

1) Unique Physical Linking

$t_i = P_{ii} \, v_i$ — Local Variable Is Global Variable

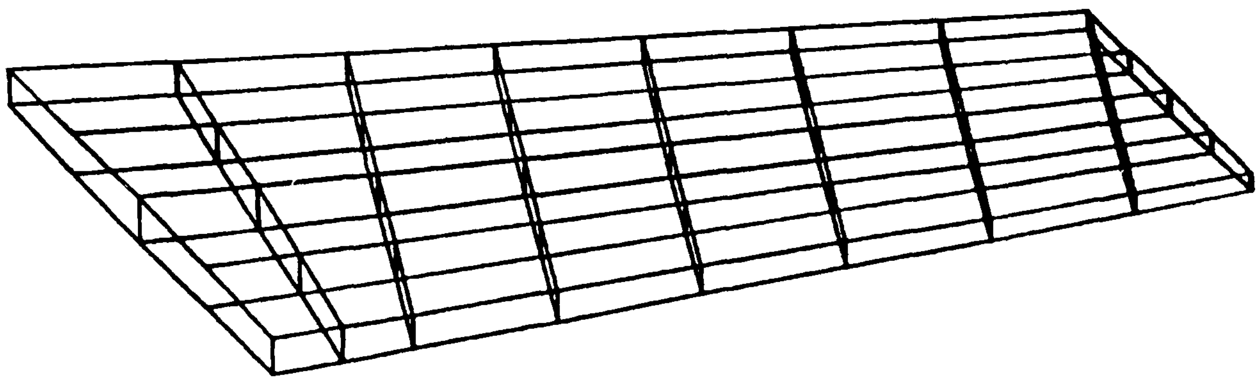
2) Physical Linking

$\{\, t_n \,\} = \{\, P_{ni} \,\} \; V_i$ — Many Local Variables Linked to One Global Variable

3) Shape Function Linking

$\{\, t \,\} = [\, P \,] \{\, v \,\}$ — Columns of [P] Are Reduced Basis Vectors

NO. OF NODES	NO. OF ELEMENTS		NO. OF DOF'S	
88	39	RODS	294	CONSTRAINED
	55	SHEAR PANELS	234	UNCONSTRAINED
	62	QUADRILATERAL MEMBRANE	528	TOTAL
	2	TRIANGULAR MEMBRANE		
	158	TOTAL		



Linking Options for Cover Skins

Unique Linking	-	256 Design Variables
Physical Linking By Ribs	-	64 Design Variables
Shape Function Linking	-	16 Design Variables

Constant Chordwise + Spanwise Taper

Thickness Constraints

- **Side Constraints**
  - Used for Unique and Physical Linking
  - Aplied to the Global Design Variable
  - Defined By Physical Limits, Manufacturing Considerations or Factors Not Analyzed in ASTROS
- **Thickness Constraints**
  - Used for Shape Function Linking
  - Explicitly Applied as a Property or Connectivity Attribute
- **Move Limits**
  - Restrain Movement of the Approximate Problem
  - Imposed Internally in ASTROS

STRESS/STRAIN CONSTRAINTS
TWO BASIC TYPES OF CONSTRAINTS:

VON MISES

$$G = \left[\left(\frac{\sigma_x}{X}\right)^2 + \left(\frac{\sigma_y}{Y}\right)^2 - \left(\frac{\sigma_x \, \sigma_y}{X \;\, Y}\right) + \left(\frac{\tau_{xy}}{S}\right)^2 \right]^{1/2} - 1.0$$

WHERE X, Y AND S ARE ALLOWABLES

FOR AN ISOTROPIC MATERIAL:

- X AND Y ARE THE SAME
- SEPARATE TENSION AND COMPRESSION ALLOWABLES
- MAT1 DATA ENTRY USED FOR INPUT

FOR AN ORTHOTROPIC MATERIAL:

- SEPARATE X AND Y ALLOWABLES
- SEPARATE TENSION AND COMPRESSION ALLOWABLES
- MAT8 DATA ENTRY USED FOR INPUT

85-50057
10A, 3K

STRESS/STRAIN CONSTRAINTS

PRINCIPAL STRAIN

$$G_1 = \frac{1}{\varepsilon_{all}} \left[\frac{1}{2}(\varepsilon_x + \varepsilon_y) + \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\varepsilon_{xy}}{2}\right)^2} \right] - 1.0$$

$$G_2 = \frac{1}{\varepsilon_{all}} \left[\frac{1}{2}(\varepsilon_x + \varepsilon_y) - \sqrt{\left(\frac{\varepsilon_x - \varepsilon_y}{2}\right)^2 + \left(\frac{\varepsilon_{xy}}{2}\right)^2} \right] - 1.0$$

Compression or tension allowable is used based on the sign of the principal strain value

Two constraints are generated for each laminate

Stress/Strain Constraints (Concluded)

Tsai - Wu

For Two-Dimensional Elements the Tsai - Wu Criteria States Failure Occurs When

$$F_{11}\sigma_1^2 + 2F_{12}\sigma_1\sigma_2 + F_{22}\sigma_2^2 + F_1\sigma_1 + F_2\sigma_2 + F_{66}\tau_{12}^2 = 1.0$$

A Ratio, R , is Determined That Will Uniformly Modify a Given Stress State to Reach the Failure Boundary

The Tsai - Wu Constraint is Defined in ASTROS as:

$$g = \frac{1.0}{R} - 1.0$$

Stiffness Constraints

Constraint	Pos	Neg	Upper	Lower
Displacement	x	x	x	x
Frequency	x	NM	x	x
Flutter	x	x	x	NM
Lift Effectiveness	x	x	x	x
Aileron Effectiveness	x	x	x	x

NM - Not Meaningful

Sensitivity Analysis

- Gradient Information Required for Automated Design

$$\frac{\partial F}{\partial V_i} \quad , \quad \frac{\partial g_j}{\partial V_i} \qquad \begin{array}{l} i = 1 , ndv \\ j = 1 , ncon \end{array}$$

- Gradients of the Objective are Invariant

- Gradients of the Constrained are All Computed Analytically

  - Key to Performing the Approximate Problem
  - Computations Can Be Intricate

Architectural Highlights

- **Executive System**
  - Provides High Level Control
  - Enables Multidisciplinary Design
- **Database**
  - Customized for Engineering Analysis and Design
  - Necessitated Major Recoding of Software Resources
- **Dynamic Memory**
  - Enables Unrestricted Problem Size
  - Provides Programmer with Precise, Explicit Control

Architectural Highlights - Concluded

- **Utility Library**
  - Special Purpose Routines Required By Modules (Sort, Search, etc.)
  - Emphasis Placed on High Quality, Robust, Self Documented Algorithms
  - Machine Dependent Functions Isolated

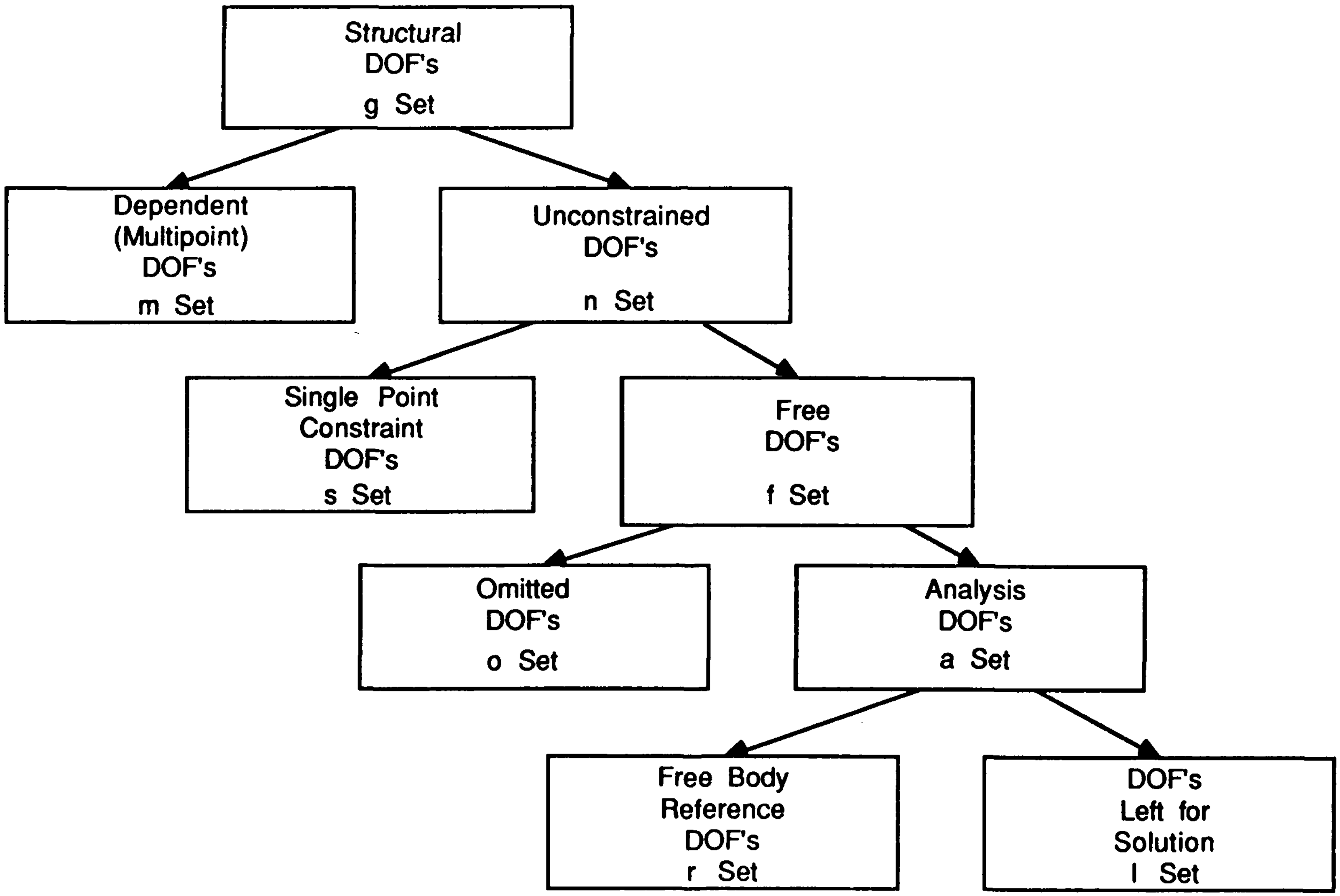
- **Modules**
  - Distinction Between Functional and Utility Modules Blurred
  - Each Module :

    Establishes Base Address in Memory
    Opens Required Data Base Entities
    Closes All Data Base Entities Prior to Exit
    Frees All Memory Blocks Prior to Exit
  - Intermodular Communication is Through the Data Base

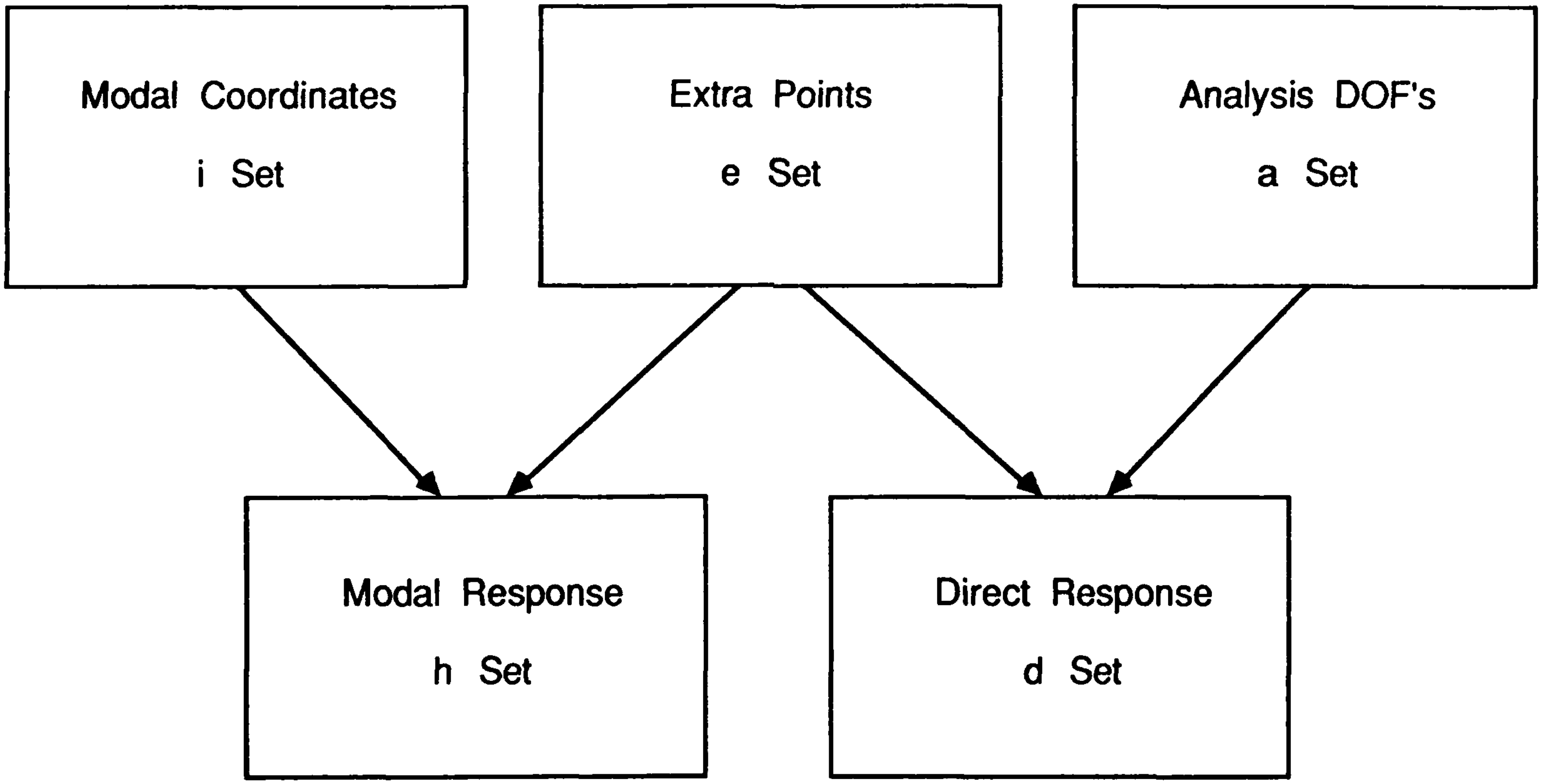
Large Matrix Utilities

UTILITY	FUNCTION
PARTN	$[A] \rightarrow \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}$
MERGE	$[A] \leftarrow \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix}$
SDCOMP	$[A] \rightarrow [L][D][L]^T$
FBS	$[X] = ([L][D][L]^T)^{-1}\ [B]$
DECOMP	$[A] \rightarrow [L][U]$
GFBS	$[X] = ([L][U])^{-1}\ [B]$
MXADD	$[C] = \alpha[A] + \beta[B]$
MPYAD	$[D] = [A][B] + [C]$
TRNSPOSE	$[B] = [A]^T$
REIG	$[K - \lambda M][\phi] = [0]$

Hierarchy Of Displacement Sets



Relation Of Dynamic Analysis Sets



Matrix And Vector Notation

TERM	(M)ATRIX OR (V)ECTOR	DESIGNATION
B	M	Damping
D	M	Rigid body transformation
G	M	Transformation matrix, including spline matrices for steady aerodynamics
K	M	Structural stiffness
M	M	Mass
m	M	Rigid body mass
P	V/M	Applied load
t	V	Local thickness variables
u	V/M	Displacement
UG	M	Unsteady aerodynamic spline
v	V	Global design variables
YS	V	Enforced displacements

Finite Elements - Concentrated Mass

- **Contain Mass Without Stiffness**
  - Used to Develop Mass Model
  - Can Be Used as " TUNING " Masses in Design
- **Two Input Forms**
  - Entire Mass Matrix at a Designated Grid Point (CONM1)
  - Mass and Inertias Input at a Point Relative to a Grid Point (CONM2)
  - Only the CONM2 Allows Design

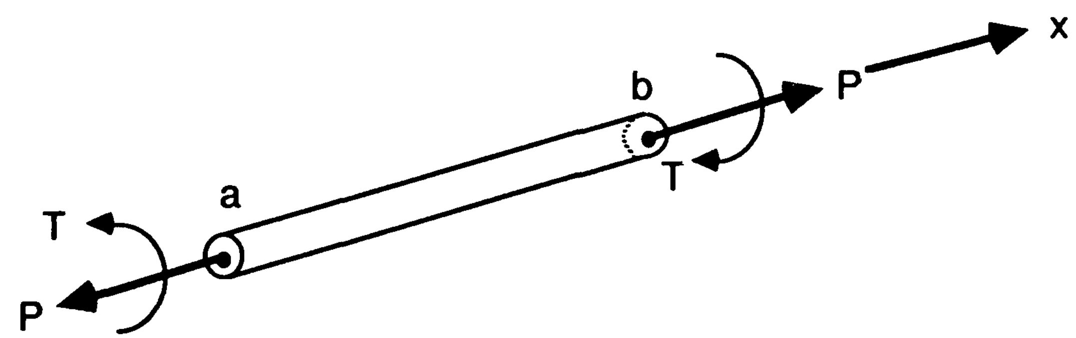
Finite Element - Scalar Elements

- ASTROS Has Implemented the NASTRAN CELAS and CMASS Elements:

$$[k] = \bar{k} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$$

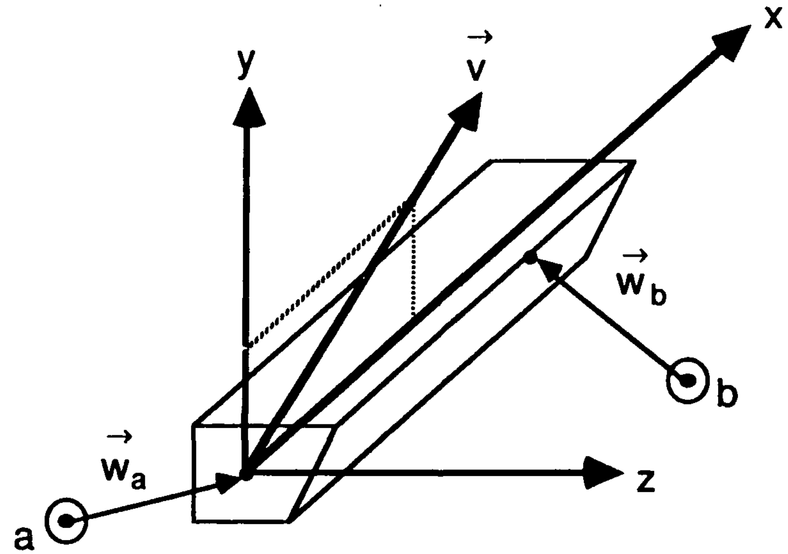
- Both Elements Can Be Designed
- Elements Have No Explicity Associated Constraints

Finite Elements - The Rod Element

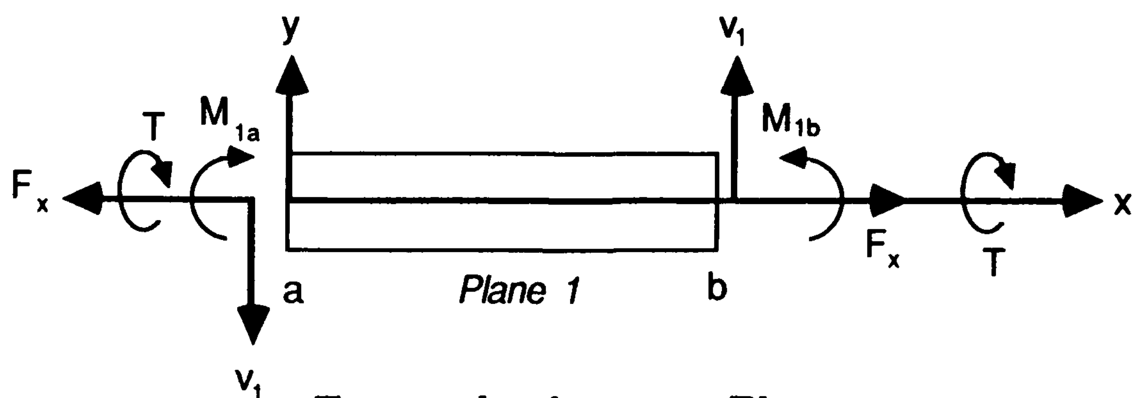


- **Two Degrees of Freedom at Each Node**
- **Design Variable is Rod Area. If the Element is Designed :**
  - Torsional Stiffness is Ignored
  - Non - Structural Mass is Ignored

Finite Elements - The Bar Element



The Element Coordinate System



Forces in the x - y Plane

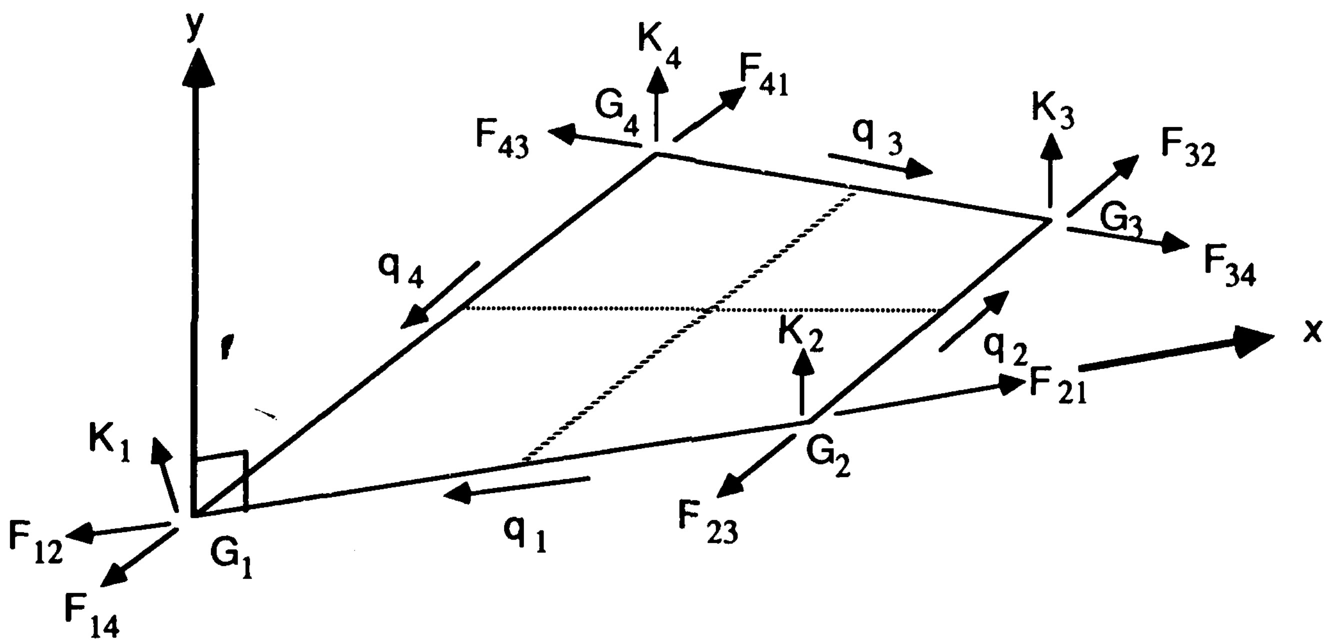
Finite Elements - The Bar Element

- **Neutral Axis May Be Offset**
- **Pinned Connections May Be Defined**
- **Stress Calculated at Four Points at Each Node**
- **Design Variable is Bar Area. - Inertias Related By**

$$I_1 = r_1^2 A^{\alpha}$$
$$I_2 = r_2^2 A^{\alpha}$$

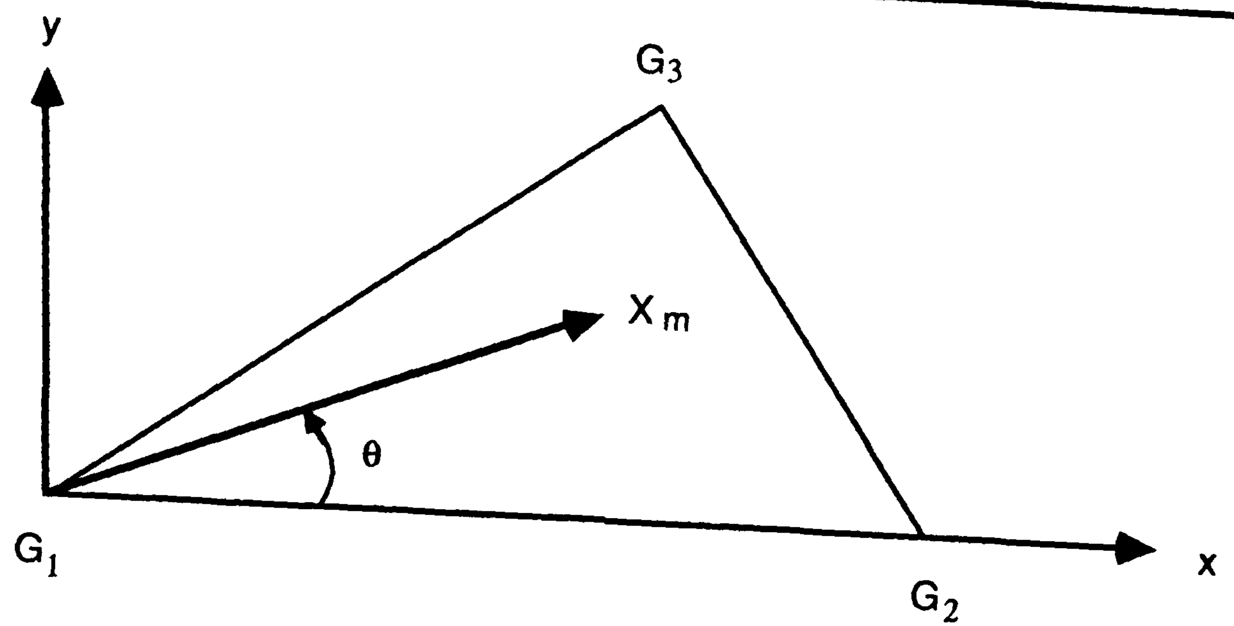
- **If the Element is Designed :**
  - Torsional Stiffness is Ignored
  - Non - Structural Mass is Ignored
  - Pin Connection and Offset Not Supported

Finite Elements - The Quadrilateral Shear Element



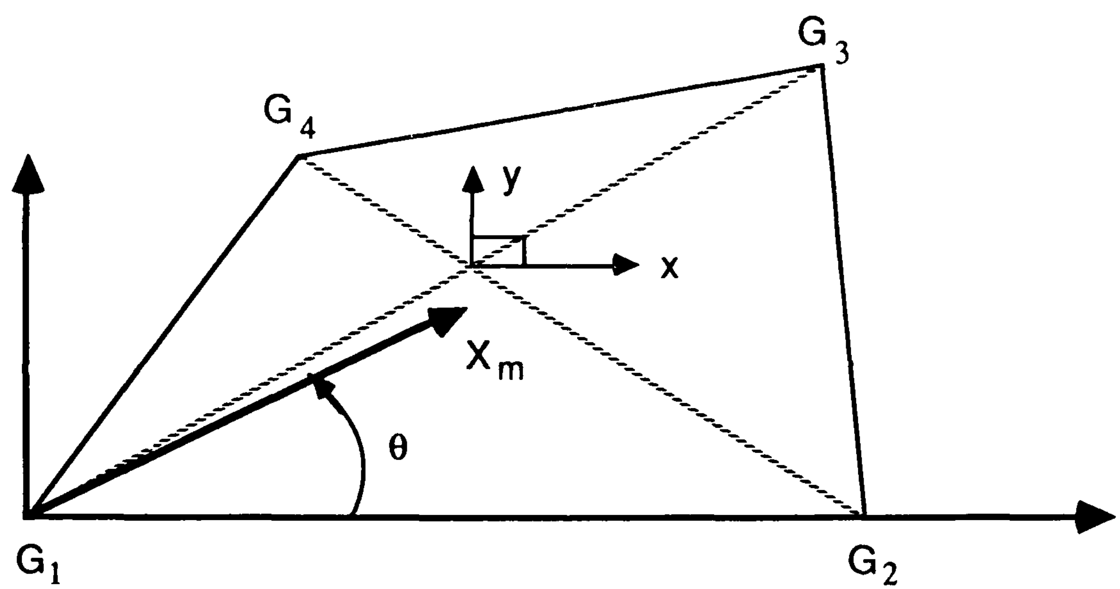
- Garvey Shear Panel Implemented
- Only Isotropic Materials Supported
- Design Variable is Element Thickness
- Stress Constraint Based on the Average Shear Stress at the Four Nodes

Finite Elements - The Triangular Membrane Element



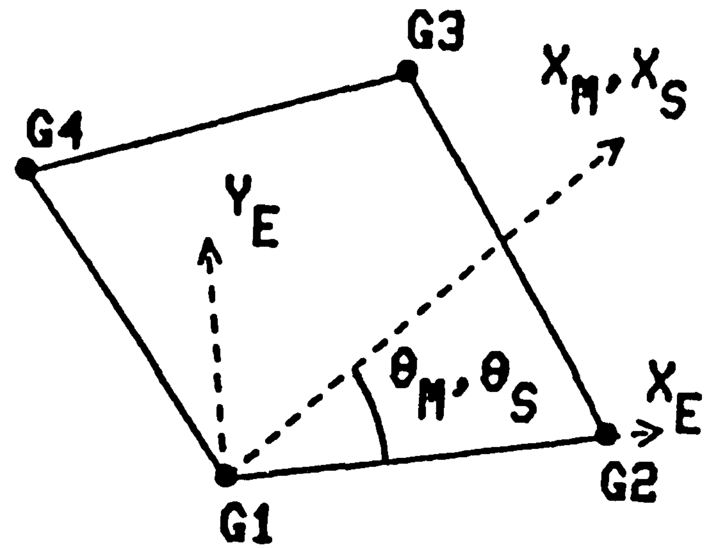
- Element Resists Only In - Plane Forces
- Linear Displacement Field $\Longrightarrow$ Constant Strain
- Anisotropic Materials Supported
- Design Variable is Element Thickness
  - Ply Direction Can Be Independently Designed
  - Orientation Angle Not a Design Variable
  - Ply Order Effect Not Accounted For

Finite Elements - The Isoparametric Quadrilateral Membrane Element



- Element Resists Only In - Plane Forces
- Equivalent to NASTRAN's CQDMEM1
- Element Warping is Allowed
- Anisotropic Materials Supported
- Design Variable is Element Thickness
  - Comments from Triangular Element Apply

Finite Elements - The Quadrilateral Shell Element



- Element Includes Efrects of Membrane, Bending, Transverse Shear with Coupling Effects
- Capable of Representing Laminate Composite Elements
- Design Variable is Element Thickness
    - Only Membrane Effects Considered in Design
    - Comments from Triangular Element Apply

COMPARISON OF QUAD4 ELEMENTS

ASTROS, MSC/NASTRAN[1] AND COSMIC NASTRAN

TEST DESCRIPTION	ELEMENT LOADING		ELEMENT SHAPE	ASTROS	MSC	COSMIC
	IN-PLANE	OUT-OF-PLANE				
1. PATCH TEST	X		IRREGULAR	A	A	A
2. PATCH TEST		X	IRREGULAR	A	A	D
3. STRAIGHT BEAM, EXTENSION	X		ALL	A	A	A
4. STRAIGHT BEAM, BENDING	X		REGULAR	B	B	F
5. STRAIGHT BEAM, BENDING	X		IRREGULAR	F	F	F
6. STRAIGHT BEAM, BENDING		X	REGULAR	A	A	B
7. STRAIGHT BEAM, BENDING		X	IRREGULAR	A	B	B
8. STRAIGHT BEAM, TWIST			ALL	B	B	D
9. CURVED BEAM	X		REGULAR	C	C	F
10. CURVED BEAM		X	REGULAR	B	B	D
11. TWISTED BEAM	X	X	REGULAR	A	A	F
12. RECTANGULAR PLATE (N=4)		X	REGULAR	A	B	C
13. SCORDELIS-LO ROOF (N=4)	X	X	REGULAR	B	B	D
14. SPHERICAL SHELL (N=8)	X	X	REGULAR	A	A	A
15. THICK-WALLED CYLINDER	X		REGULAR	B	F	F

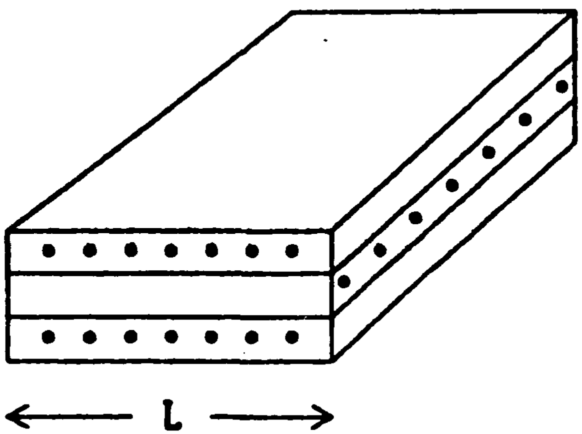
[1] MSC/NASTRAN IS A SERVICE AND TRADEMARK OF MACNEAL-SCHWENDLER CORP.

[2] MSC REPORTED ERROR EXCEEDS 50%, THUS GRADE SCORE IS CORRECTED TO "F".

GRADE SCORES ARE DEFINED BY:
A - ERROR LESS THAN 2%
B - ERROR BETWEEN 2% AND 10%
C - ERROR BETWEEN 10% AND 20%
D - ERROR BETWEEN 20% AND 50%
F - ERROR EXCEEDS 50%

ASTROS INTERIM REVIEW — ISOPARAMETRIC QUADRILATERAL ELEMENT

SAMPLE TEST PROBLEM FOR LAMINATED COMPOSITE PLATE



REGULAR SYMMETRIC
CROSS-PLY LAMINATE

SIMPLY SUPPORTED
UNIFORM LOAD

$T_1 = T_2 = T_3 = 0.06667$

$E_1 = 2.0E7$ $\quad L = 1.0$

$E_1 = 5.0E5$ $\quad P = 1.0E-4$

$NU_{12} = 0.25$ $\quad \theta_1 = \theta_3 = 0.0°$

$G_{12} = 2.5E5$ $\quad \theta_2 = 90°$

STRESS RESULTS		
LAYER 1&3	ASTROS Q4	THEORY
σ_1	53.6	58.6
σ_2	1.4	1.8
τ_{12}	-.04	-.06

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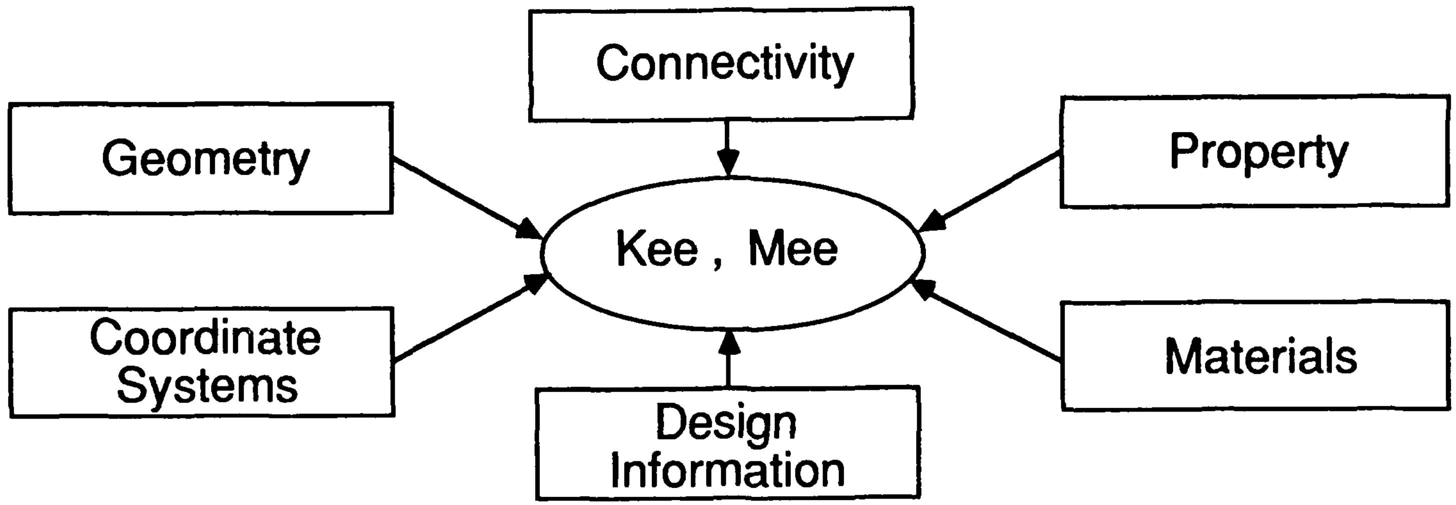
Matrix Assembly - Stage One

- **Matrices are Assembled at the Element Level**



- **Performed as a Preface Operation**

Matrix Assembly - Stage Two

- **Design Sensitivity Matrices are Assembled**

$$[DKV]_i = \sum_{j=1}^{nle} p_{ij} [KEE]_j$$

$$[DMV]_i = \sum_{j=1}^{nle} p_{ij} [MEE]_j$$

nle = Number of Linked Elements

- **Performed as a Preface Operation**
- **These Matrices are Basic to ASTROS Sensitivity Analysis**

Matrix Assembly - Stage Three

- **Global Matrices are Assembled**

$$[K_{gg}] = \sum_{i=0}^{ndv} v_i \, [DKV]_i + \sum_{j=1}^{ndv} v_j^{\alpha j} \, [DKBV]_j$$

$$[M_{gg}] = \sum_{i=0}^{ndv} v_i \, [DMV]_i$$

- **Assembly is Performed Inside the Design Loop**

Static Loads - Capability

- **Mechanical Loads**
  - Discrete Forces and Moments at Grids
  - Pressure Loads Defined by Three or Four Grids
- **Gravity Loads**
  - User Defined Acceleration Vector
  - Can Be Design Dependent

$$\{DPGR\}_i = [DMV]_i \{a_g\}$$

- **Thermal Loads**
  - Temperature Specified at Grid Points
  - Can Be Design Dependent

$$\{DPTH\}_i = \sum_{j=1}^{nle} p_{ij} [T_{ee}]_j \{T_{GRID} - T_{REF}\}_j$$

Static Loads - Assembly

- **ASTROS Allows For the Combination of Simple Loads**

$$\{P_g\} = S_0 \sum_i S_i \{L\}_i$$

- **Final Assembly is Performed Inside the Design and Boundary Condition Loops**
  - Allows for Combining of Simple Loads
  - Accommodates Design Dependent Loads

Static Analysis - Equations Of Motion

- **Equilibrium Equation in the g - set :**

$$[K_{gg}]\{u_g\} + [M_{gg}]\{\ddot{u}_g\} = \{P_g\}$$

- **NASTRAN Formulation Followed For MPC, SPC and Guyan Reduction**

- **Support Reduction Aligned with NASTRAN's Static Aeroelastic Analysis**

  - Deformations are Constrained To Be Orthogonal to Rigid Body Mode Shapes

$$[D \quad I]^T \begin{bmatrix} M_{\ell\ell} & M_{\ell r} \\ M_{r\ell} & M_{rr} \end{bmatrix} \begin{Bmatrix} u_\ell \\ u_r \end{Bmatrix} = 0$$

Where

$$[D] = -[K_{\ell\ell}]^{-1}[K_{\ell r}]$$

Static Analysis - Solution And Recovery

- **With Rigid Body Degrees of Freedom :**

$$\begin{bmatrix} K_{\ell\ell} & K_{\ell r} & M_{\ell\ell} D + M_{\ell r} \\ D^T M_{\ell\ell} + M_{r\ell} & D^T M_{\ell r} + M_{rr} & 0 \\ 0 & 0 & m_r \end{bmatrix} \begin{Bmatrix} u_\ell \\ u_r \\ \ddot{u}_r \end{Bmatrix} = \begin{Bmatrix} P_\ell \\ 0 \\ D^T P_\ell + P_r \end{Bmatrix}$$

- **Otherwise :**

$$[K_{aa}]\{u_a\} = \{P_a\}$$

- **Recovery to g - set is Standard**

Static Analysis - Strength Constraint Evaluation

Element	Von - Mises	Tsai - Wu	Principal Strain
BAR	X		
QDMEM1	X	X	X
QUAD4	X	X	X
ROD	X		X
SHEAR	X		X
TRMEM	X	X	X

- **ASTROS Computes a Design Invariant Matrix Which Relates Stress / Strain to Global Displacements**

$$\{\sigma\} = [SMAT]^T \{u_g\}$$

Static Analysis - Strength Constraint Example

- **For the Triangular Membrane Element at Each Node**

$$[S_i] = [G]\,[C_i]\,[E]^T\,[T_i] \qquad i = 1, 2, 3$$

[G]	-	Stress / Strain
[C]	-	Strain - Displacement
[E]	-	Basic to Element Coordinate Transformation
[T]	-	Basic to Global Coordinate Transformation

- **Then the Element Stress is**

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \sum_{i=1}^{3} [S_i]\,\{U_{gi}\}$$

Static Analysis - Strength Constraint Sensitivity

- **Constraints are a Function of Design Variables and Structural Deformation**

$$g = f(u, v)$$

- **Sensitivity to a Design Variable is :**

$$\frac{\partial g_j}{\partial v_i} = \frac{\partial f_j}{\partial v_i} + \frac{\partial f_j^T}{\partial u} \frac{\partial u}{\partial v_i}$$

Non - Zero Only
For Thickness Constraints

Obtained By
Chain Rule Differentiation

Gradient Method For Sensitivity Analysis - Overview

- **Solves**

$$[K]\left\{\frac{\partial u}{\partial v}\right\} = \left\{\frac{\partial P}{\partial v}\right\} - \left[\frac{\partial K}{\partial v}\right]\{u\}$$

- **Forms**

$$\frac{\partial g}{\partial v} = \frac{\partial f}{\partial u}^{T} \frac{\partial u}{\partial v}$$

- **Number of Forward - Backward Substitutions Equal to the Number of Design Variables Times the Number of Load Cases**

- **Method is General**

Virtual Load Method For Sensitivity Analysis

- **Solves**

$$[K]\{w\} = \left\{\frac{\partial f}{\partial u}\right\}$$

- **Forms**

$$\frac{\partial g}{\partial v} = \{w\}^T \left[\left\{\frac{\partial P}{\partial v}\right\} - \left[\frac{\partial K}{\partial v}\right]\{u\}\right]$$

- **Number of Forward - Backward Substitutions Equal to the Number of Constraints**
- **Method Not Applicable With Inertia on Aerodynamic Terms**

Sensitivity Analysis - Gradient Method

- The Gradient of the Equilibrium Equation Gives

$$[K_{gg}]\left\{\frac{\partial u_g}{\partial v}\right\} + [M_{gg}]\left\{\frac{\partial \ddot{u}_g}{\partial v}\right\} = \left\{\frac{\partial P_g}{\partial v}\right\} - \left[\frac{\partial K_{gg}}{\partial v}\right]\{u_g\} - \left[\frac{\partial M_{gg}}{\partial v}\right]\{\ddot{u}_g\}$$

- Terms on the Right Hand Side are Known

$$\left\{\frac{\partial P_g}{\partial v_i}\right\} = \{DPGR\}_i + \{DPTH\}_i$$

$$\left[\frac{\partial K_{gg}}{\partial v_i}\right] = [DKV]_i + \alpha v_i^{(\alpha-1)}[DKBV]_i$$

$$\left[\frac{\partial M_{gg}}{\partial v_i}\right] = [DMV]_i$$

- These are Pseudo-Load Vectors that are Designated DP_g

Sensitivity Analysis - Gradient Method (Continued)

- **With Support, Gradient of Orthogonality Constraint Gives :**

$$[\,D \quad I\,]^T \begin{bmatrix} M_{\ell\ell} & M_{\ell r} \\ M_{r\ell} & M_{rr} \end{bmatrix} \begin{Bmatrix} DU_\ell \\ DU_r \end{Bmatrix} = -[\,D \quad I\,]^T \begin{Bmatrix} DMU_\ell \\ DMU_r \end{Bmatrix}$$

Where

$$DU = \partial u / \partial v$$

$$DMU = \left[\frac{\partial M}{\partial v} \right] \{ u \}$$

- **Leads to Sensitivity Equations Similar to the Analysis Equations**

$$\begin{bmatrix} K_{\ell\ell} & K_{\ell r} & M_{\ell\ell} D + M_{\ell r} \\ D^T M_{\ell\ell} + M_{r\ell} & D^T M_{\ell r} + M_{rr} & 0 \\ 0 & 0 & m_r \end{bmatrix} \begin{Bmatrix} DU_\ell \\ DU_r \\ DUD_r \end{Bmatrix}_i = \begin{Bmatrix} DP_\ell \\ D^T DMU_\ell + DMU_r \\ D^T DP_\ell + DP_r \end{Bmatrix}_i$$

Sensitivity Analysis - Gradient Method (Concluded)

- Gradients of Displacements in the f - set are Recovered From Gradients of Displacements and Accelerations in the a - set

- Sensitivity of Constraints With Respect to g - set Displacements are Reduced to the f - set

- This Results in Fewer Terms in the Vector Multiply to Obtain Constraint Gradients

$$\frac{\partial g_j}{\partial v_i} = \frac{\partial f_j}{\partial u_f}^T \frac{\partial u_f}{\partial v_i}$$

Modal Analysis

- **Determines Structural Eigenvalues and Eigenvectors**

$$[K_{aa} - \lambda M_{aa}]\{\Phi_a\} = 0$$

- **Useful in Its Own Right, But Also :**
  - Basis For Frequency Constraints
  - Flutter and Blast Analyses Always Use Modal Coordinates
  - Transient, Frequency and Gust Analysis Can Use Modal Formulation

- **Given's (Tridiagonal) Method of Eigenanalysis Employed**
- **Problem Size is Typically Reduced**
  - Guyan Reduction
  - Dynamic Reduction

Dynamic Reduction

- Reduces the Number of Freedom Without the Explicit Selection of Retained Degrees of Freedom

- Gives Comparable or Better Accuracy for Modal Analysis With Fewer Degrees of Freedom

- Generalized Dynamic Degrees of Freedom are Made up of Any or All of the Following:

  1) Physical Degrees of Freedom
  2) Inertia Relief Shapes
  3) Approximate Mode Shapes

Dynamic Reduction - Approximate Mode Shapes

- **Subspace Vectors are Generated Using Iteration**

$$[K - \lambda_s M] \{u_{i+1}\} = \frac{1}{c_i} [M] \{u_i\}$$

- **Process Converges to the Eigenvector Whose Eigenvalue is Closed to λ_s**
- **Previous Iterates Contain Nearby Eigenvectors**
- **Algorithm Performance Dependent on Specification of**
  - Starting Vector
  - Number of Iterates
  - Shift Point
  - Rejection of Parallel Vectors

Dynamic Reduction - Approximate Mode Shapes (Concluded)

- **Reduction is Performed Using**

$$\{u_f\} = [G_{fk}]\{u_k\}$$

u_k - Generalized Degree of Freedom

G_{fk} - Matrix of Approximate Eigenvectors

- **ASTROS Applications Have Produced Excellent, But Limited Results**

Frequency Constraint Evaluation

Constraints on Frequency Can Be Upper Bound

$$g_j = 1.0 - \frac{\left(2\pi f_{high}\right)^2}{\lambda_j}$$

Or Lower Bound

$$g_j = \frac{\left(2\pi f_{low}\right)^2}{\lambda_j} - 1.0$$

Structural Frequencies Can Be Squeezed Into a Range But Not Squeezed Out

Frequency Constraint Sensitivity

For Upper Bound Constraint

$$\frac{\partial g_j}{\partial v_i} = \frac{(2\pi f_{HIGH})^2}{\lambda_j^2} \frac{\partial \lambda_j}{\partial v_i} = \frac{(1.0 - g_j)}{\lambda_j} \frac{\partial \lambda_j}{\partial v_i}$$

Where

$$\frac{\partial \lambda_j}{\partial v_i} = \{\phi_j\}^T \left[\frac{\partial K}{\partial v_i} - \lambda_j \frac{\partial M}{\partial v_i}\right] \{\phi_j\} / (\{\phi_j\}^T [M] \{\phi_j\})$$

Steady Aerodynamics

- **ASTROS Has Incorporated the USSAERO - C Computer Code**

- **Features Include**

  Subsonic and Supersonic Analyses
  Symmetric and Antisymmetric Analyses
  Multiple Lifting Surfaces
  Body Elements for Fuselage and Pods
  Thickness and Camber Effects
  Aerodynamic Influence Coefficients
  Multiple Mach Numbers

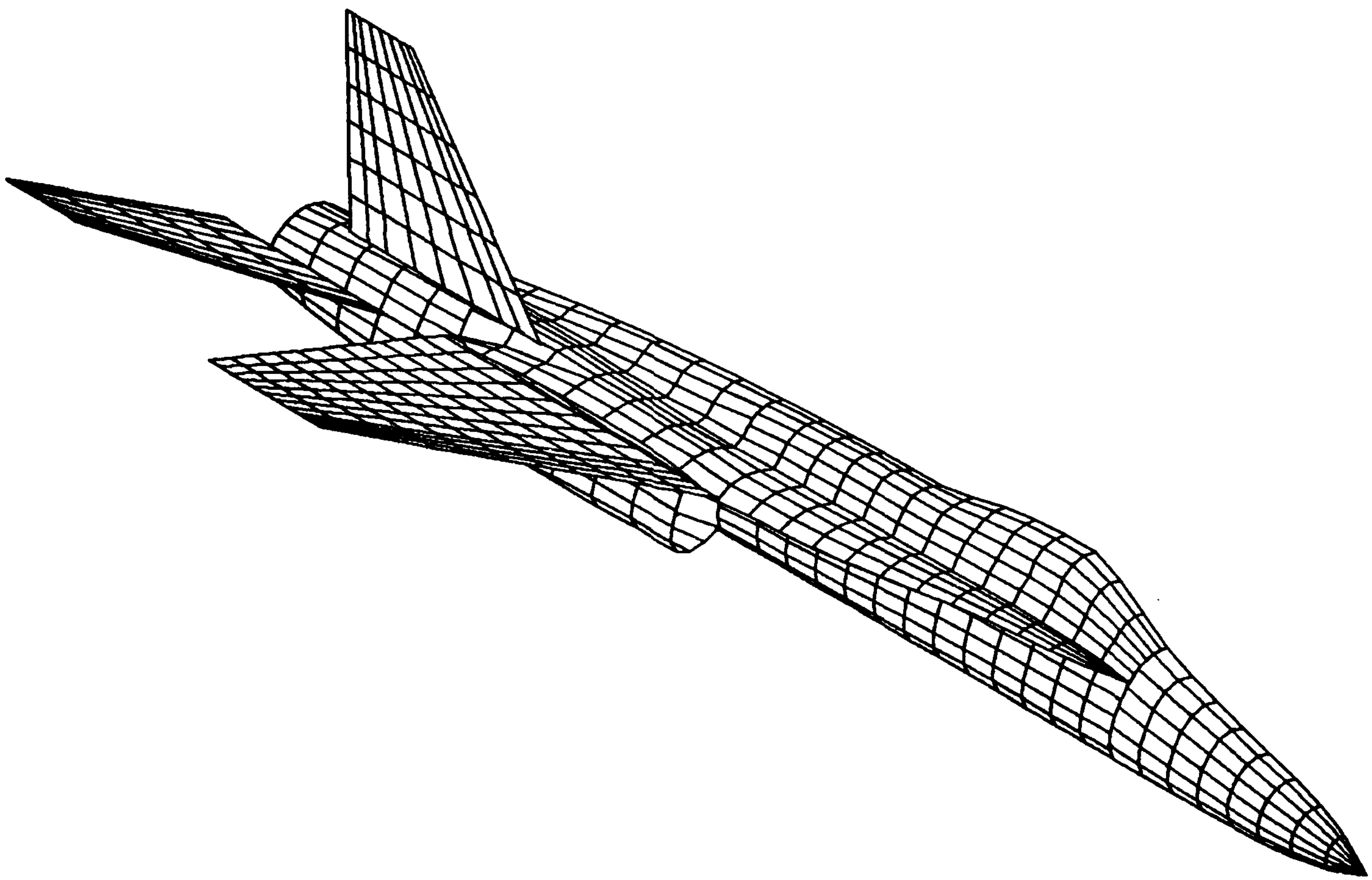
Steady Aerodynamics

- Aircraft Configuration is Modeled By Discrete Panels
- Singularities at Panels are Solved For as a Function of the Boundary Condition

$$\begin{bmatrix} A_{bb} & A_{bw} \\ A_{wb} & A_{ww} \end{bmatrix} \begin{Bmatrix} \sigma \\ \gamma \end{Bmatrix} = \begin{Bmatrix} \omega_b \\ \omega_w \end{Bmatrix}$$

- Singularities $\Longrightarrow$ Velocities $\Longrightarrow$ Pressures $\Longrightarrow$ Forces
- Rigid Aerodynamic Forces are Computed For a Series of Boundary Conditions
- Aerodynamic Influence Coefficient Matrix Based on Linearized Pressure Computation

Steady Aerodynamics - Paneling Example



Unsteady Aerodynamics

- **Two Paneling Methods Have Been Implemented :**

  Doublet Lattice For Subsonic Aerodynamics

  Constant Pressure Method For Supersonic Aerodynamics

  A Common Geometric Definition is Utilized

- **Features Include**

  Symmetric, Antisymmetric and Asymmetric Analyses

  Slender Bodies and Interference Panels For Subsonic Aerodynamics

  No Bodies For Supersonic Aerodynamics

  Multiple Lifting Surfaces

Unsteady Aerodynamics

Preface Aerodynamics Compute Three Basic Matrices

A - Computes Downwash For Given Pressures

$$w = [A]\,P$$

D - Computes Downwash For Given Displacements

$$w = [D]\,U$$

S - Computes Forces For Given Pressures

$$F = [S]\,P$$

Subsequent Disciplines Require Different Matrices

Fluttered Gust : $[Q_{hh}] = [\phi\, G^T\, SA^{-1}\, DG\phi]$

Gust : $[Q_{hj}] = [\phi\, G^T\, SA^{-1}]$

Blast: $[A]^{-1}$

Design Independent Calculations are Performed Only Once

Connection Between Aerodynamic And Structural Models

- **Aerodynamic and Structural Points are Typically Not Coincident**

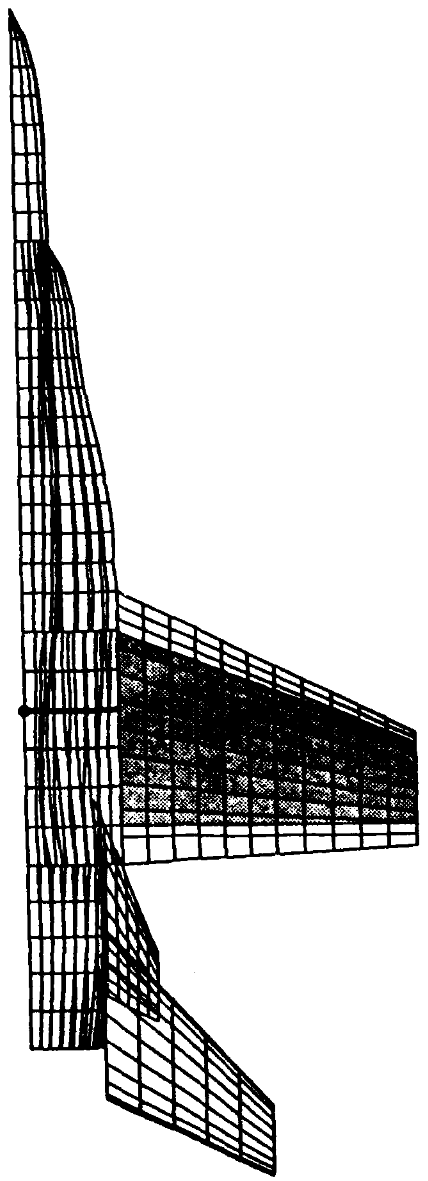
- **Two Techniques are Available for Transfer of Deformations and Forces**
  - Surface Spline Technique
  - Equivalent Force Transfer

Surface Spline

- Developed By Harder and Desmaris and Applied in NASTRAN
- Solves Equation For an Infinite Plate to Provide Deformations of a Continuous Surface Based on Deformations at a Discrete Set of Points

UNSTEADY	***STEADY***
$\{w_a\} = [UG]\{w_s\}$	$\{\alpha_a\} = [GS]\{w_s\}$
$\{F_s\} = [UG]^T\{F_a\}$	$\{F_s\} = [G]\{F_a\}$
w - Deformation	a - Aero Model
α - Slope	s - Structural Model

Equivalent Load Transfer



Used When No Underlying Structural Model Exists For Aerodynamic Components

Geometrically Based Transfer :

$$\{F\}_R = \sum_{i=1}^{NBOX} \{F\}_i$$

$$\{M\}_R = \sum_{i=1}^{NBOX} [R]_i \{F\}_i$$

Where

$$[R]_i = \begin{bmatrix} 0 & -(z_i - z_R) & (y_i - y_R) \\ (z_i - z_R) & 0 & -(x_i - x_R) \\ -(y_i - y_R) & (x_i - x_R) & 0 \end{bmatrix}$$

Static Aeroelastic Analysis

The Aerodynamic Loads Contain a Rigid Portion

$$[PA_f] = \bar{q}\, [G_{jf}]^T\, [AIRFRC]$$

And a Portion Related Structural Deformation

$$[AICS_{ff}] = \bar{q}\, [G_{jf}]^T\, [AIC]\, [GS_{jf}]$$

The Equilibrium Equation is Then

$$[K_{ff} - AICS_{ff}]\{u_f\} + [M_{ff}]\{\ddot{u}_f\} = [PA_f]\, \{\delta\}$$

A New Matrix Combines Structural and Aerodynamic Stiffnesses

$$[KA_{ff}] = [K_{ff} - AICS_{ff}]$$

Static Aeroelastic Analysis

The Solution of the Aeroelastic Equations Resembles That of Static Analysis

$$\left[\begin{array}{cc|c} KA_{\ell\ell} & KA_{\ell r} & M_{\ell\ell}D+M_{\ell r} \\ D^T M_{\ell\ell}+M_{r\ell} & D^T M_{\ell r}+M_{rr} & 0 \\ \hline D^T KA_{\ell\ell}+KA_{r\ell} & D^T KA_{\ell r}+KA_{rr} & m_r \end{array}\right] \left\{\begin{array}{c} u_\ell \\ u_r \\ \hline \ddot{u}_r \end{array}\right\} = \left[\begin{array}{c} PA_\ell \\ 0 \\ \hline D^T PA_\ell + PA_r \end{array}\right] \{\delta\}$$

A Notational Change Gives

$$\begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} = \begin{bmatrix} P_1 \\ P_2 \end{bmatrix} \{\delta\}$$

The First Equation is Solved for u_1 and Substituted Into the Second to Give

$$[K_{22} - K_{21}K_{11}^{-1}K_{12}]\,\{u_2\} = [P_2 - K_{21}K_{11}^{-1}P_1]\,\{\delta\}$$

This is the Basic Equation For Static Aeroelastic Analysis

Static Aeroelastic Analysis - Symmetric Trim

For Symmetric Analysis, the δ Vector Has Four Components

- o - Thickness and Camber Effects
- δ_e - Pitch Control Surface
- q - Pitch Rate
- α - Angle of Attack

Single Equation Trim :

Lift Equation is Balanced

Pitch Rate and Pitch Control are Ignored

u_2 is a Scalar Equal to $g\,n_z$

α is Determined That Provides Required Lift

Static Aeroelastic Analysis - Symmetric Trim

Two Equation Trim

Lift and Pitching Moment are Balanced

Pitch Acceleration is Zero

Vertical Acceleration is $g\,n_z$

$$q = \frac{g\,(n_z - 1)}{V}$$

α and δ_e are Determined

Given u_2 and δ , Recovery of Displacements and Stresses is Straightforward

Lift Effectiveness Constraint

Bounds are Placed on the Flexible to Rigid Lift Curve Slope

$$\epsilon_{min} \leq \frac{C_{L_{\alpha_f}}}{C_{L_{\alpha_R}}} \leq \epsilon_{max}$$

Flexible Derivatives are Obtained From Basic Equation

$$\frac{\bar{q}S}{2}\begin{Bmatrix} C_{L_{\alpha_f}} \\ cC_{m_{\alpha_f}} \end{Bmatrix} = [m_r][K_{22}-K_{21}K_{11}^{-1}K_{12}]^{-1}[P_2-K_{21}K_{11}^{-1}P_1]\{\delta_\alpha\} \Leftarrow \begin{matrix}\text{Unit } \alpha \\ \text{Other Components} \\ \text{Zero}\end{matrix}$$

Includes Inertia Relief and Aeroelastic Effects

Rigid Derivatives are Obtained From

$$\frac{\bar{q}S}{2}\begin{Bmatrix} C_{L_{\alpha_R}} \\ \hline cC_{m_{\alpha_R}} \end{Bmatrix} = [P_2]\{\delta_\alpha\}$$

Lift Effectiveness Constraint (Concluded)

Effectiveness Affected By Dynamic Pressure But is Independent of Trim Requirements

A Positive Lower Bound Limit on Effectiveness Creates the Constraint

$$g = 1.0 - \epsilon / \epsilon_{REQ}$$

Upper Bound, Negative and Zero Requirements Can Also Be Specified

Antisymmetric Aeroelastic Analysis

For Antisymmetric Analysis, the δ Vector Has Two Components

δ_a - Roll Control Surface

p - Roll Pitch Rate

Analysis Computes Aircraft Roll Effectiveness

$$\epsilon_{eff} = -\left(C_{\ell_{\delta a}}\right)_f / \left(\frac{C_{\ell_{pb}}}{2V}\right)_f$$

Measures Steady State Roll Achievable for a Unit Aileron Deflection

Roll Effectiveness Constraint

Flexible Derivatives are Calculated From

$$\frac{\bar{q}Sb}{2} C_{\ell_{\delta a}} = [P_2 - K_{21}K_{11}^{-1}P_1] \begin{Bmatrix} 1.0 \\ 0.0 \end{Bmatrix}$$

$$\frac{\bar{q}Sb^2}{4} C_{\ell_{\frac{pb}{2V}}} = [P_2 - K_{21}K_{11}^{-1}P_1] \begin{Bmatrix} 0.0 \\ 1.0 \end{Bmatrix}$$

Constraint Form and Capabilities Similar to Lift Effectiveness

Static Aeroelasticity - Sensitivity Analysis

Similar to Sensitivity of Static Analysis Without Aerodynamics

- Aerodynamic Matrices are Invariant with Respect to Design Variables
- Calculation Varies Depending on the Condition

Basic Equation is

$$\left[\begin{array}{cc|c} KA_{\ell\ell} & KA_{\ell r} & M_{\ell\ell}D+M_{\ell r} \\ D^TM_{\ell\ell}+M_{r\ell} & D^TM_{\ell r}+M_{rr} & 0 \\ \hline D^TKA_{\ell\ell}+KA_{r\ell} & D^TKA_{\ \ r}+KA_{rr} & m_r \end{array}\right] \left\{\begin{array}{c} Du_\ell \\ Du_r \\ \hline DUD_r \end{array}\right\}_i = \left[\begin{array}{c} PA_\ell \\ 0 \\ \hline D^TPA_\ell+PA_r \end{array}\right] \{DDEL\}_i$$

$$+ \left\{\begin{array}{c} DP_\ell \\ D^TDMU_\ell+DMU_r \\ \hline D^TDP_\ell+DP_r \end{array}\right\}$$

Static Aeroelasticity - Sensitivity Analysis

For Trim Sensitivity

Acceleration is Invariant

Compute Change in Trim Settings

Change in Displacements Then Extracted

For Lift Effectiveness Sensitivity

Configuration Parameters are Invariant

Changes in Accelerations and Displacement are Computed

For Roll Effectiveness Sensitivity

Configuration Parameters are Invariant

Acceleration is Invariant and Zero

Changes in Displacement are Computed

Flutter Analysis

p − k METHOD OF FLUTTER ANALYSIS EMPLOYED

$$\left[p^2 \left(\frac{V}{b}\right)^2 M_{HH} + K_{HH} - \rho \frac{V^2}{2}\left(\frac{p}{k} Q^I_{HH} + Q^R_{HH}\right)\right] \{v\} = 0$$

WHERE

$$p = k\ (\gamma + i)$$

$$M_{HH} = \Phi^T M \Phi$$

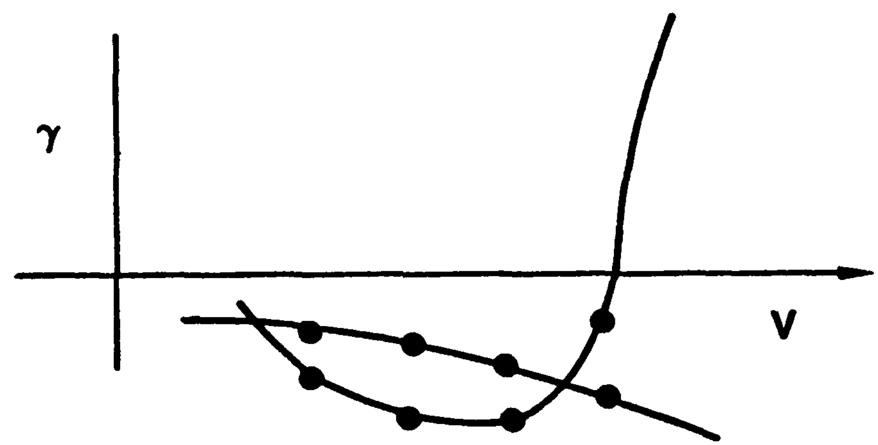
$$K_{HH} = \Phi^T K \Phi$$

$$Q_{HH} = \Phi^T G^T S A^{-1} D G \Phi$$

THE EQUATION REPRESENTS A SYNTHESIS OF NASTRAN AND FASTOP

Flutter Analysis

p – k METHOD SOLVES FOR p AT A SET OF SPECIFIED VELOCITIES



FASTOP ALGORITHM EMPLOYED TO SOLVE EQUATION

MULLER'S METHOD WITH DEFLATION

MODIFIED TO EXTRACT REAL ROOTS

GIVEN p:

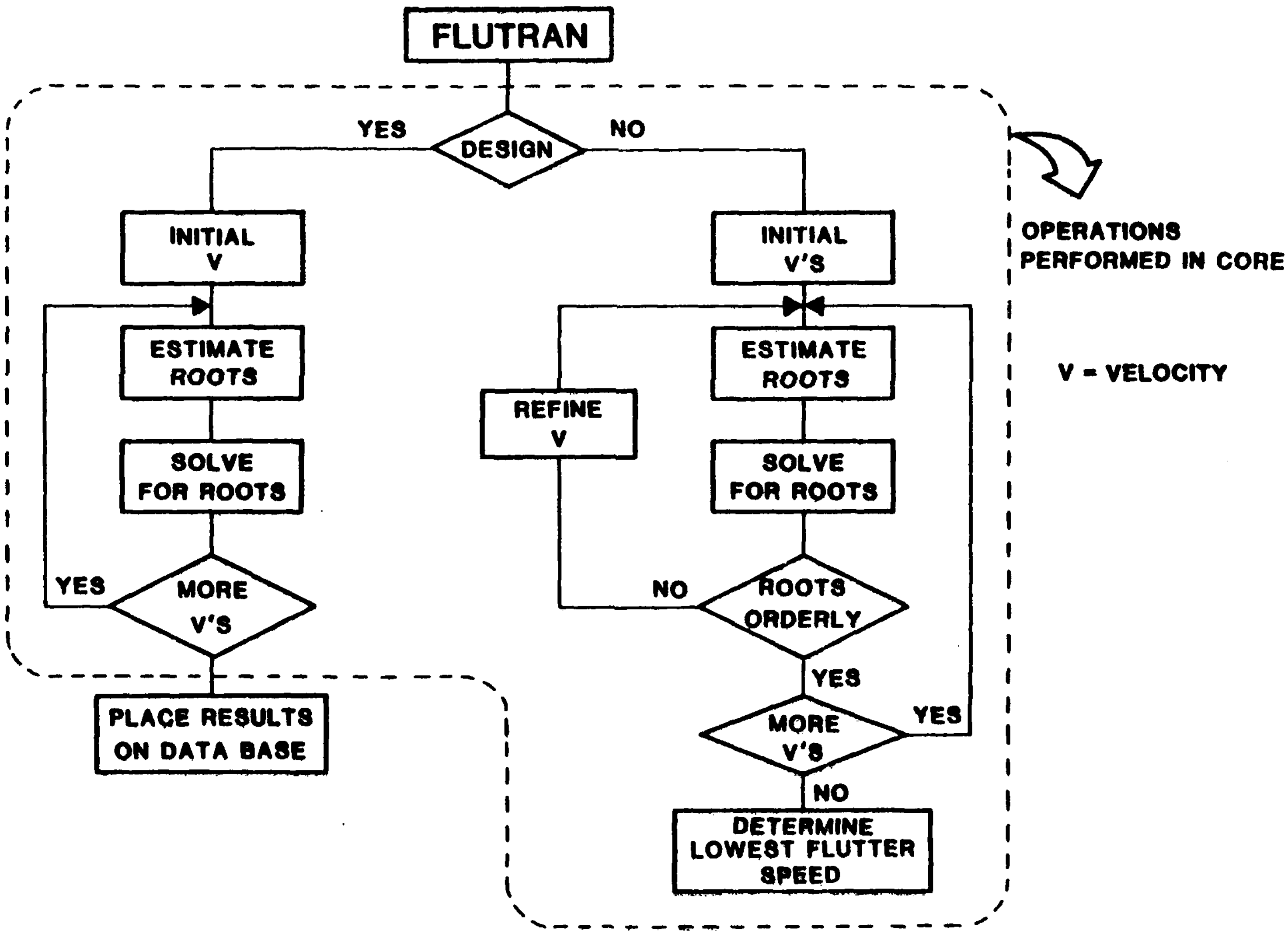
$$k = \text{Imag}(p)$$

$$\gamma = \text{Real}(p)/k$$

Flutter Analysis - Aerodynamic Interpolation

- Aerodynamics Have Been Computed at a Discrete Set of Reduced Frequencies
- p - k Method Assumes Aerodynamics are Available as a Continuous Function of Reduced Frequency
- A Cubic Spline Fit of the Aerodynamics, Adapted From NASTRAN, is Used for Interpolation
- Quality of the Interpolation is Assessed By the Procedure

Flutter Analysis Algorithms



Flutter Constraint Form

$$g = \frac{\gamma - \gamma_{REQ}}{GFACT} \leq 0.0$$

Where

γ - Extracted Damping Value

$$= \frac{Re\,(p)}{k} \quad \text{For Oscillatory Roots}$$

$$= \frac{p}{\ell n\, 2} \quad \text{For Real Roots}$$

γ_{REQ} - Required Damping Value Which Can Be a Function of Velocity

GFACT - Normalization Factor

NOTE : IT IS NOT NECESSARY TO KNOW THE FLUTTER SPEED

Flutter Constraint Properties

- Computation of the Flutter Speed Not Required
- Constraint Evaluated Only at Velocities of Interest
- " Hump " Mode Behavior is Addressed
- Typically, Only a Few Constraints Require Gradients

Flutter Constraint Sensitivity

The Gradient of the Flutter Constraint is Given By

$$\frac{\partial g}{\partial v_i} = \frac{1}{GFACT} \frac{\partial \gamma_{j1}}{\partial v_i}$$

The Gradient of the Damping Value is Given By

$$\frac{\partial \gamma_{j1}}{\partial v_i} = \frac{1}{k} \left(\frac{\partial Re(p)}{\partial v_i} - \gamma_j \frac{\partial Im(p)}{\partial v_i} \right)$$

Gradient is Computed Analytically

Sensitivity of the Normal Modes is Not Required

Adjoint Flutter Vector Utilized

Similar to Frequency Constraint Sensitivity

Procedure is Conceptually Straightforward But Algebraically Complex

Automated Design - Methods Of Solution

Mathematical Programming

- Search for the Optimum Based on Currently Available Information
- General in Application
- Computationally Intensive

Fully Stressed Design

- Redesigns Based on an Optimality Criterion
- Computationally Efficient
- Limited in Application

Mathematical Programming

ASTROS Employs the MICRO - DOT Code

Combines Features of Feasible Directions and Generalized Reduced Gradient

One - Dimensional Search Based on Polynomial Interpolation with Bounds

Other Algorithms Could Be Readily Substituted

Reduction In The Number Of Design Variables

- **Design Variable Linking**
  - Reduces Size of the Design Task
  - Allows Consideration of Physical Limitations
- **There are No Fixed Limits on the Number of Design Variables**
  - Computer Resources a Nonlinear Function at Design Variables and Constraints
  - Practical Limits a Function of Computer Utilized and User's Tolerance Level
  - 200 - 300 Variables Taxing for a Micro Computer

Reduction In The Number Of Constraints

- **The Majority of the Constraints Do Not Affect the Redesign Task**
- **Motivation for Reduction**
  - Eases the Sensitivity Analysis Task
  - Streamlines the Redesign Task
- **Constraints are Included in Redesign if**
  - They are Greater Than ϵ
  - At Least NRFAC x ndv Constraints are Always Retained
- **Deletion of Constraints Can Result in**
  - Inactive Boundary Conditions
  - Inactive Disciplines
  - Inactive Subcases

The Approximate Design Problem

- **A Major Efficiency Results From Approximating Quantities Required in Redesign Rather Than Computing Them Explicity**

- **Five Basic Pieces of Information are Supplied to the Design Task :**

F_o	-	Current Value of the Objective
$\{v_o\}$	-	Current Values of the Design Variables
$\{g_o\}$	-	Current Values of the Retained Constraints
$\{\partial F/\partial v_i\}$	-	Gradient of the Objective with Respect to the Design Variables
$[A]$	-	Current Value of the Gradient of the Active Constraints with Repect to the Design Variables

The Approximate Design Problem

- **Assumption is Made That Constraint Gradients are Invariant with Respect to Changes in the Design Variables**

- **Quality of This Assumption is Enhanced By the Use of Inverse Design Variables**

  - $x_i = 1/v_i$

  - Motivation is that Strength Constraints are Inversely Proportional to Structural Thickness

  - Applicable to Unique and Physical Linking

Redesign Using Inverse Design Variables

Objective and Constraints are Computed as

$$F = \sum_{i=1}^{ndv} \frac{1}{x_i} \frac{\partial F}{\partial v_i}$$

$$g_j = g_{oj} - \sum_{i=1}^{ndv} \frac{A_{ji}\,(x_i - x_{oi})}{x_{oi}^2}$$

Gradients of the Objective and Constraints

$$\frac{\partial F}{\partial x_i} = - \frac{1}{x_i^2} \frac{\partial F}{\partial v_i}$$

$$\frac{\partial g_j}{\partial x_i} = - \frac{1}{x_{oi}^2} A_{ji}$$

Move Limits are Imposed on the Design Variables During Redesign

$$\frac{x_{oi}}{MOVLIM} \leq x_i \leq MOVLIM \cdot x_{oi}$$

Redesign Using Direct Design Variables

Inverse Design Variables are Not Applicable with Shape Function Linking

- Physical Significance Not Clear
- Direct Variables Can Be Zero

Objective and Constraints are Computed as

$$F = \sum_{i=1}^{ndv} v_i \frac{\partial F}{\partial v_i}$$

$$g_j = g_{oj} + \sum_{i=1}^{ndv} A_{ji} v_i$$

Gradients of the Objective and Constraints are

$$\frac{\partial F}{\partial v_i} = \frac{\partial F}{\partial v_i}$$

$$\frac{\partial g_j}{\partial v_i} = A_{ji}$$

Termination Criteria

- **MICRO - DOT Designates Approximate Problem Converged When Either**

$$|\Delta F| \leq \text{DABOBJ} \quad (.001)$$

$$|\Delta F / F| \leq \text{DELOBJ} \quad (.001)$$

In Two Sucessive Iterations

- **ASTROS Tentatively Designates Design Converged if**

$$|\Delta F| \leq .005$$

$$|\Delta F / F_0| \leq 0.1 \text{ CNVLIM} \quad (.005)$$

Termination Criteria (Concluded)

- Check Must Be Made if Constraints are Satisfied
- Design is Analyzed and Designated Converged When

$$2.0 \cdot CTL < g_{max} < 3.0 \cdot CTLMIN$$

g_{max} - Maximum Constraint Value

CTL - Active Constraint Identifier (D = -.003)

CTLMIN - Violated Constraint Identifier (D = .0005)

Fully Stressed Design Option

- Resize Local Design Variables Based on a Simple Stress Ratio

$$t_{i_{new}} = \max\left\{ \left(\sigma/\sigma_{all} \right)^{\alpha} \cdot t_{i_{old}}, t_{i_{min}} \right\}$$

- Simple Stress Ratio Obtained from Existing Stress Constraints

$$\sigma/\sigma_{all} = G + 1.0$$

- Determine New Global Variable Value from Linking Relation

$$t_i = P_{ij} \; V_j$$

$$V_{j_{new}} = \max\left\{ t_{i_{new}} / P_{ij} \right\} \text{ over all } t_i \text{ for } j \text{ th } V$$

10-12-87-08-EJ

Fully Stressed Design Option (Concluded)

- User Selects FSD Through Solution Control Optimization Strategy

- User Can Select the Number of FSD Cycles Performed Before Switching to Math Programming

- FSD is not Supported for Shape Function Design Variable Linking

10-12-87-09-EJ

Dynamic Response Analysis

- **All Dynamic Response Disciplines are Based on an Equation of the Form :**

$$[M]\,\{\ddot{u}\} + [B]\,\{\dot{u}\} + [K - qQ\}\,\{u\} = \{P(t)\} + \{C\}$$

- **Transient Response, Frequency Response and Flutter**
  - Gust Analysis
  - Fast Fourier Transform Techniques

- **Direct and Modal Formulations Available**

Dynamic Matrix Assembly Direct Forms

$$[M_{dd}] = [M^1{}_{dd}] + [M^2{}_{dd}]$$

$$[B_{dd}] = [B^2{}_{dd}] + \frac{g}{\omega_3}[K^1{}_{dd}]$$

$$[K_{dd}]^t = [K^1{}_{dd}] + [K^2{}_{dd}]$$

$$[K_{dd}]^f = (1+ig)\ [K^1{}_{dd}] + [K^2{}_{dd}]$$

Superscripts: **1** **Denotes Matrices Obtained Through Assembly of Element Matrices**

2 **Denotes Direct Input Matrices**

Dynamic Matrix Assembly
Modal Forms

$$[M_{hh}] = [\backslash m_i \backslash] + [\phi_{dh}]^T [M^2{}_{dd}] [\phi_{dh}]$$

$$[B_{hh}] = [\backslash b_i \backslash] + [\phi_{dh}]^T [B_{dd}] [\phi_{dh}]$$

$$[K_{hh}]^t = [\backslash k_i \backslash] + [\phi_{dh}]^T [K^2{}_{dd}] [\phi_{dh}]$$

$$[K_{hh}]^f = (1 + ig) [\backslash k_i \backslash] + [\phi_{dh}]^T [K^2{}_{dd}] [\phi_{dh}]$$

Where m_i are the generalized mass terms

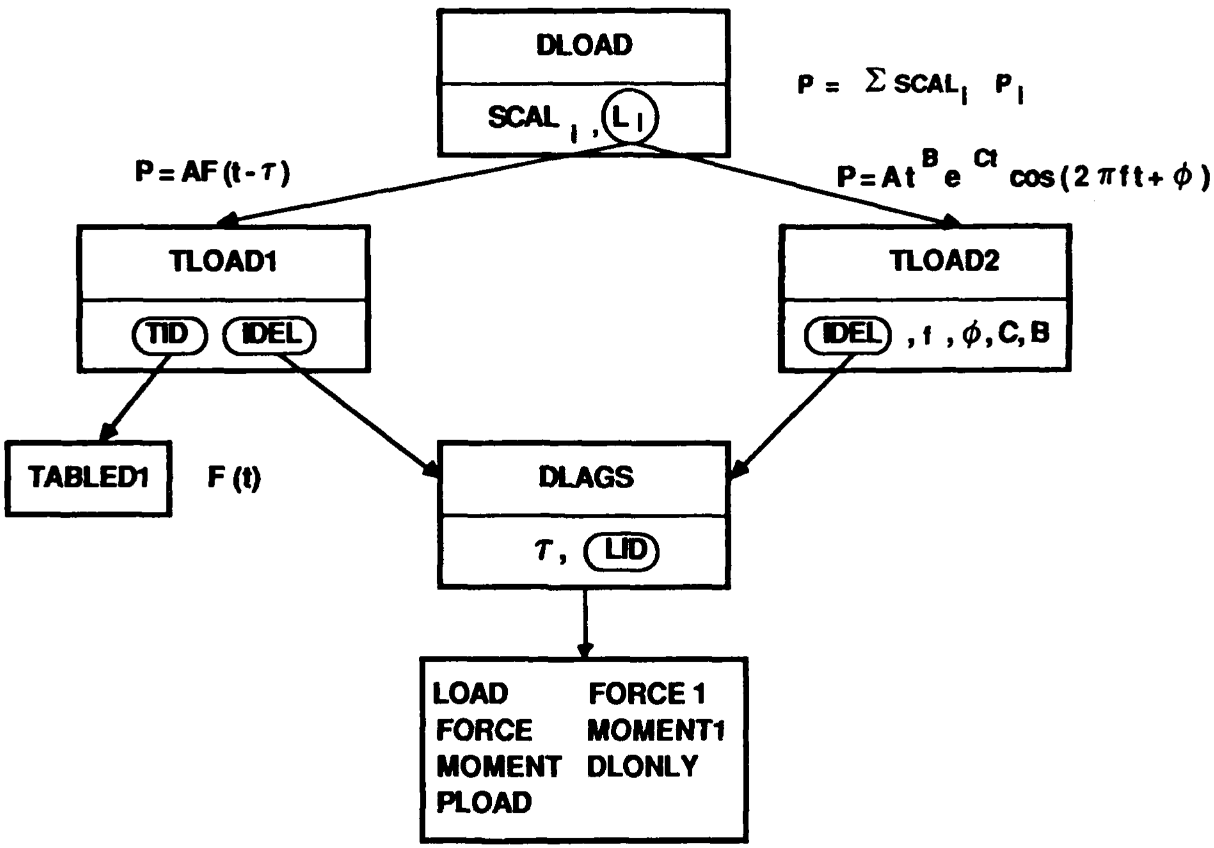
b_i are the generalized modal damping terms

k_i are the generalized stiffness terms

Dynamic Load Generation
Transient Response

$$P(x, y, z, t) = S(x, y, z)\, F(t)$$

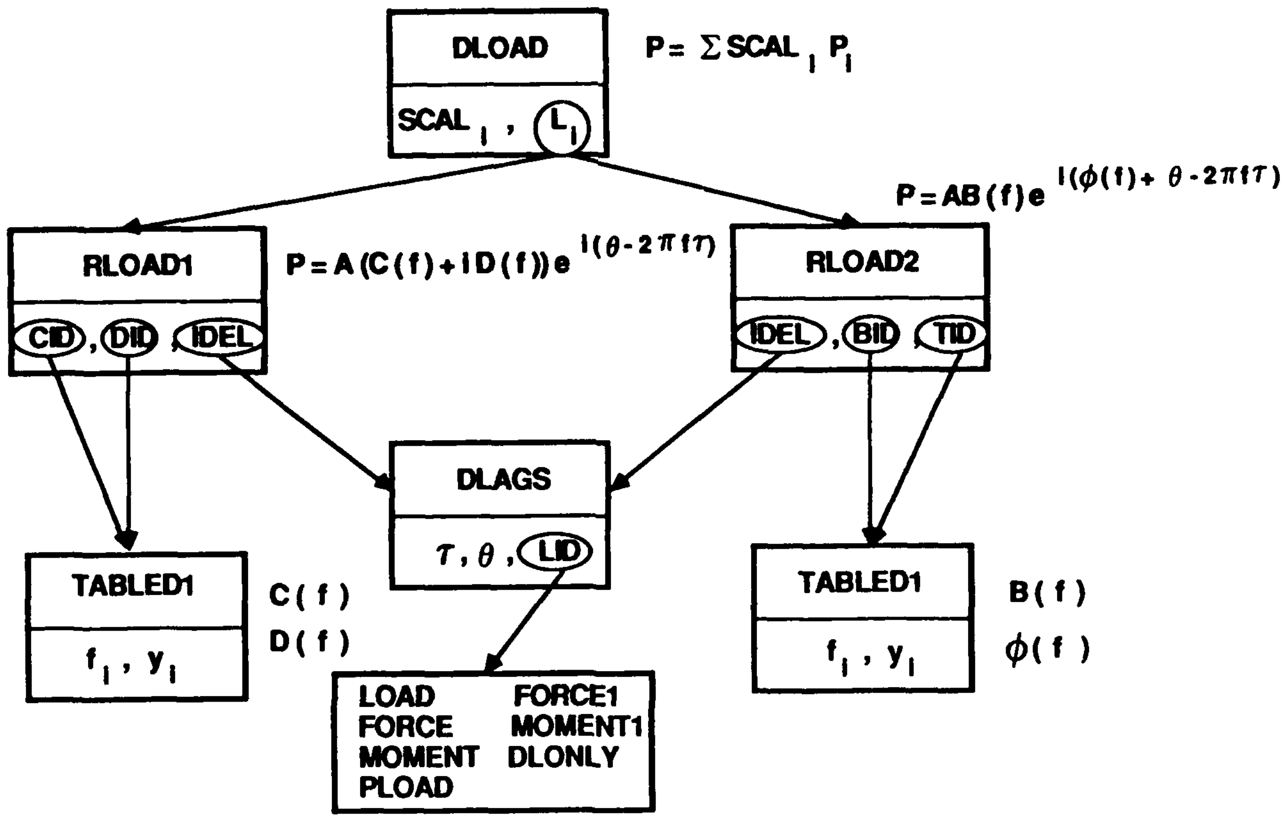
Input Flow



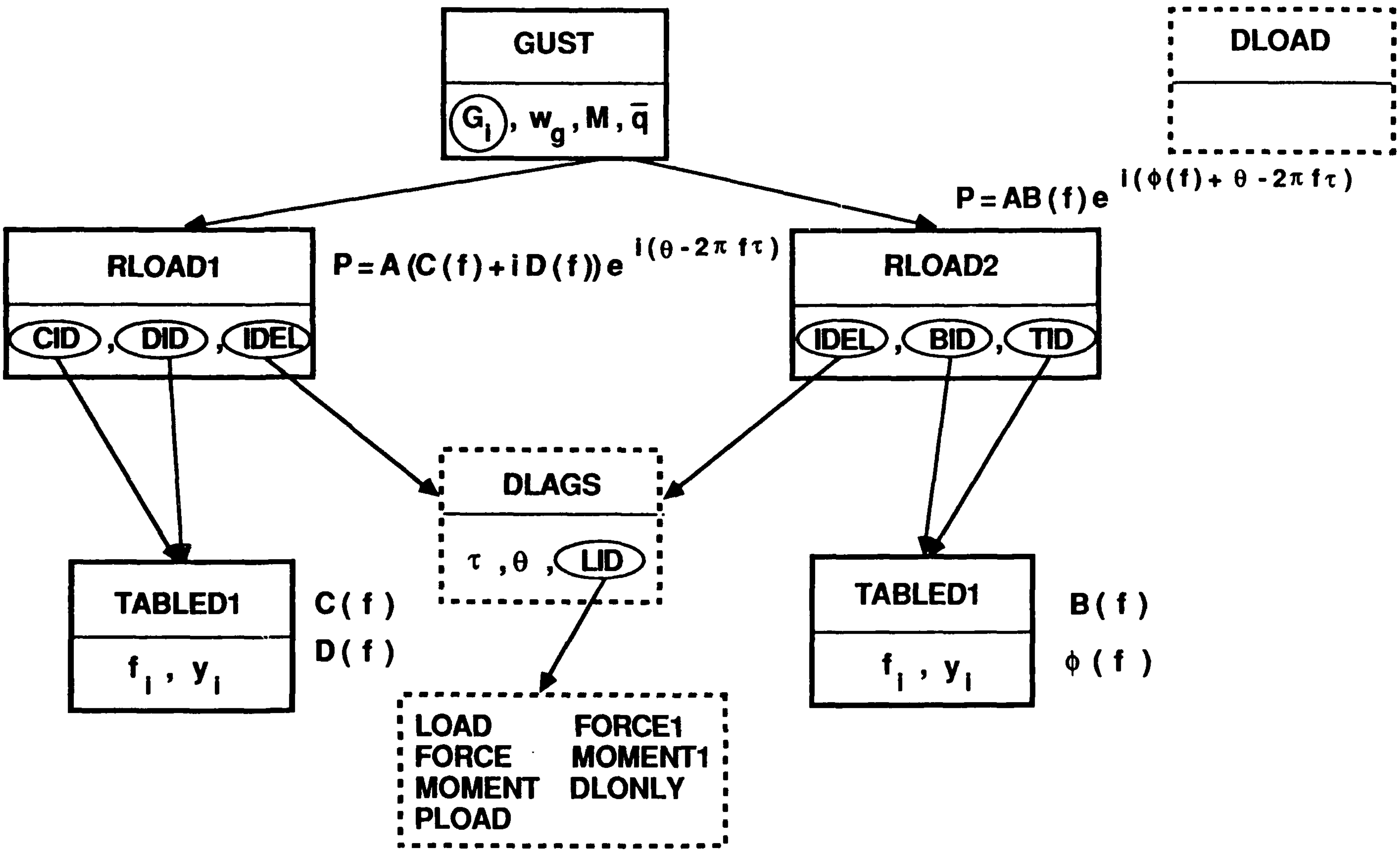
Dynamic Load Generation
Frequency Response

$$P(x,y,z,f) = S(x,y,z)\,F(f)$$

Input Flow



Dynamic Load Generation - Gust Response



Dynamic Response Solution Techniques

Uncoupled Modal - Equations Can be Solved in Closed Form

Transient Response

$$u_{i,\,n+1} = F\,u_{i,n} + G\,\dot{u}_{i,n} + A\,P_{i,n} + B\,P_{i,n+1}$$

Frequency Response

$$u_i(\omega) = \frac{P_i(\omega)}{-m_i\omega^2 + i b_i \omega + k_i}$$

Coupled Modal and Direct Equations Require Additional Complexity

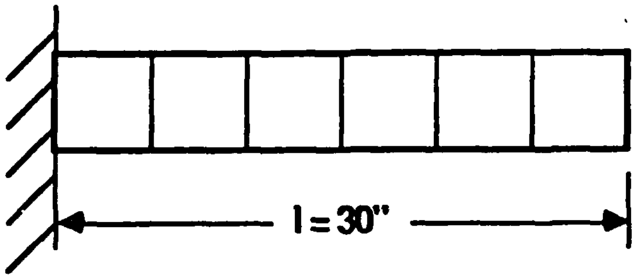
Transient Response Uses Newmark - Beta

$$[A]\{u_{n+1}\} = \frac{1}{3}\{P_{n+1} + P_n + P_{n-1}\} + [B]\{u_n\} + [C]\{u_{n-1}\}$$

Frequency Response - Decomposition and FBS of

$$[-\omega^2 M_{hh} + i\omega B_{hh} + K_{hh}]\{u_h\} = \{P_h\}$$

Transient Response with a Feedback System



Mode	Frequency (Hz)
1	4.35
2	26.47
3	72.18
4	137.0
5	275.0

Damping Matrix

$$B_{hh} = 3.18 \cdot 10^{-4} K_{hh}$$

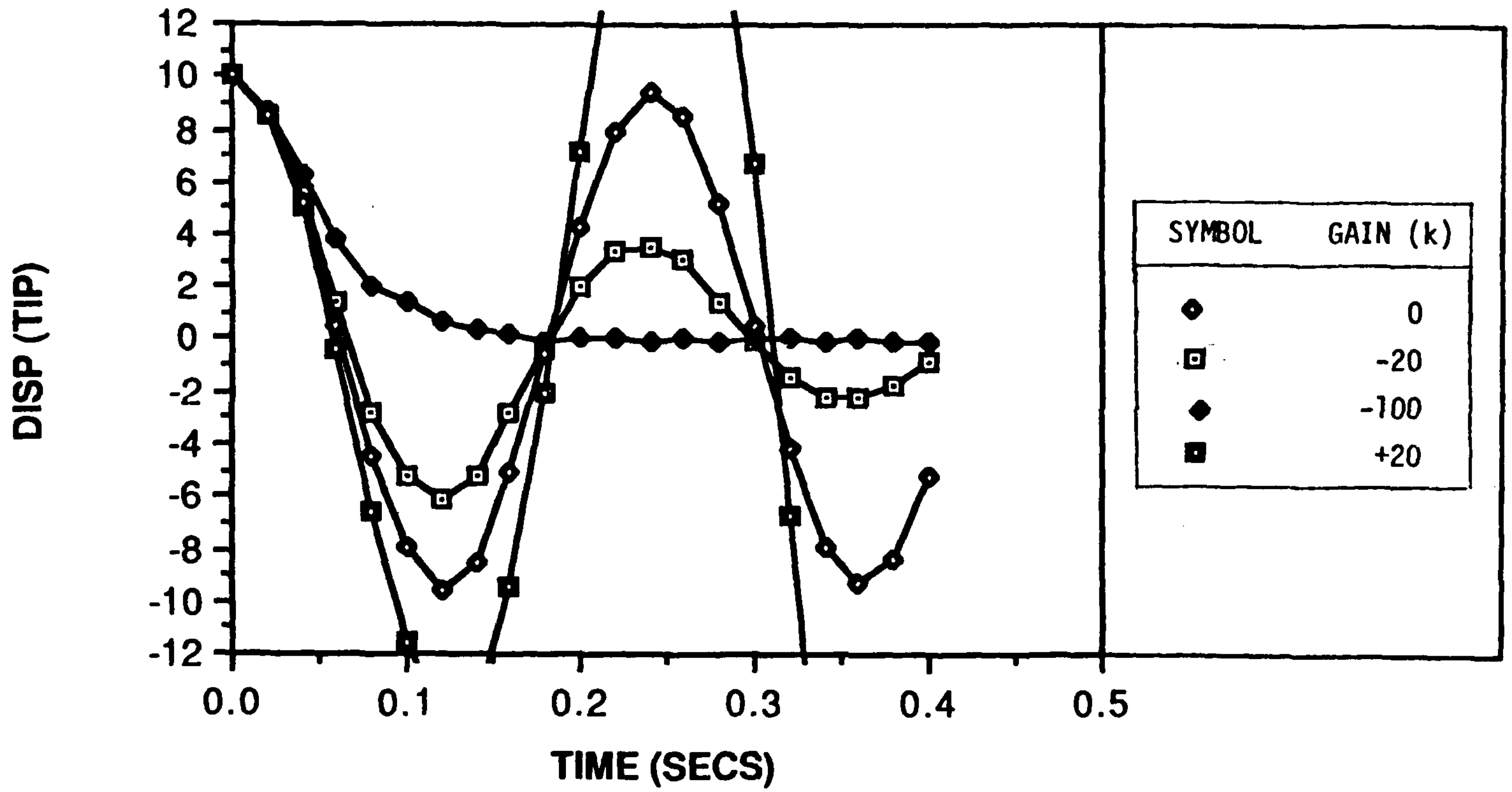
10 Inch Tip Deflection was Imposed at t = 0

Feedback System :

$$F_{TIP} = \frac{ks\, W_{TIP}}{s^2 + 100s + 10000}$$

10-16-87-01-EJ

Response as a Function of Gain



Gust Analysis

- Gust Equation :

$$\left[-\omega^2 M + i\,\omega\left(B - \frac{\bar{q}\,b}{V}\,Q^{I}(\omega)\right) + K - \bar{q}\,Q^{R}(\omega)\right]u = P(\omega)$$

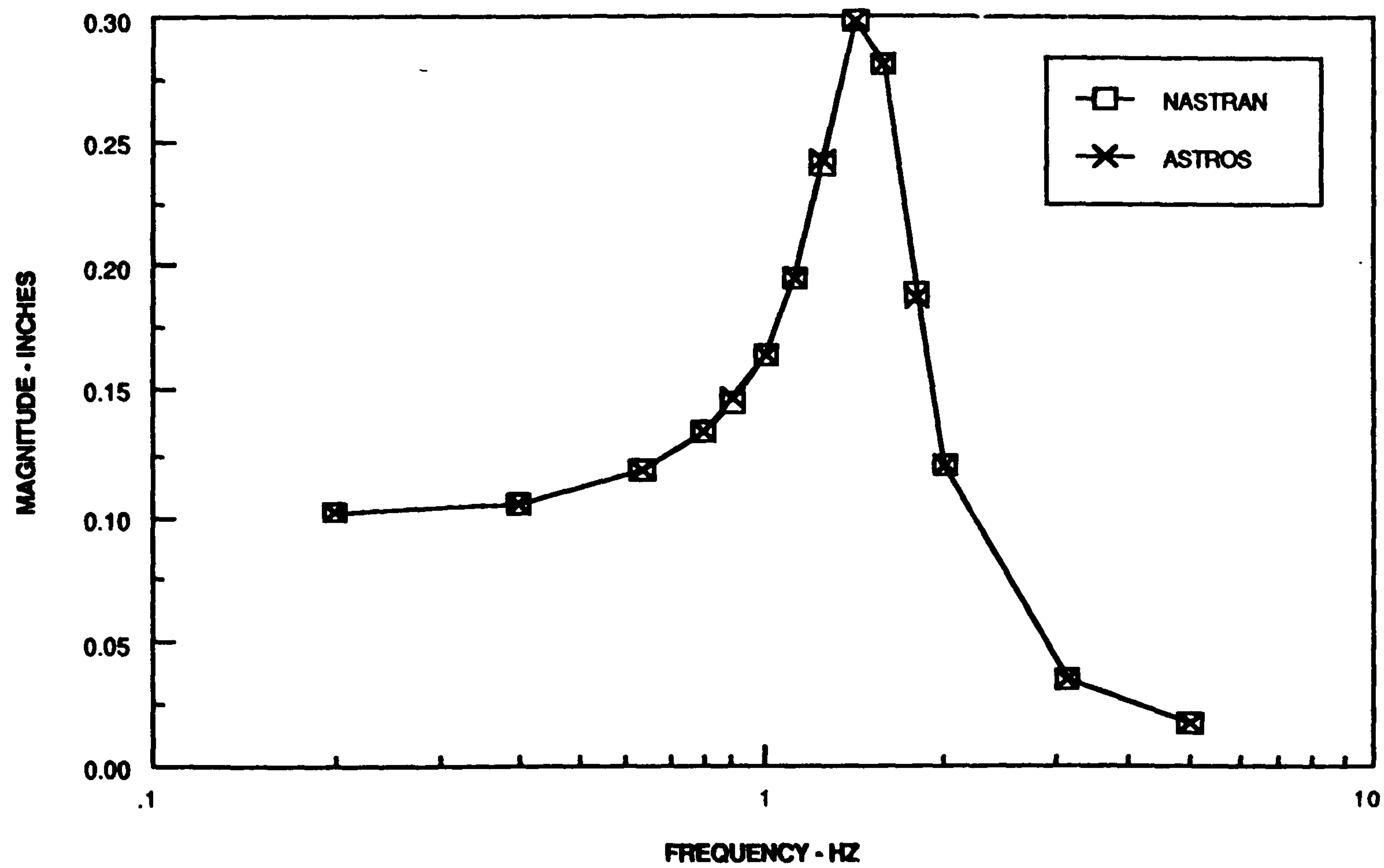
- Equation is Solved in the Frequency Domain Using the Modal Method

- Gust Loads are a Combination of :
  - Mode Shapes
  - Spline Matrix
  - Frequency Dependent Aerodynamics
  - Aircraft Geometry

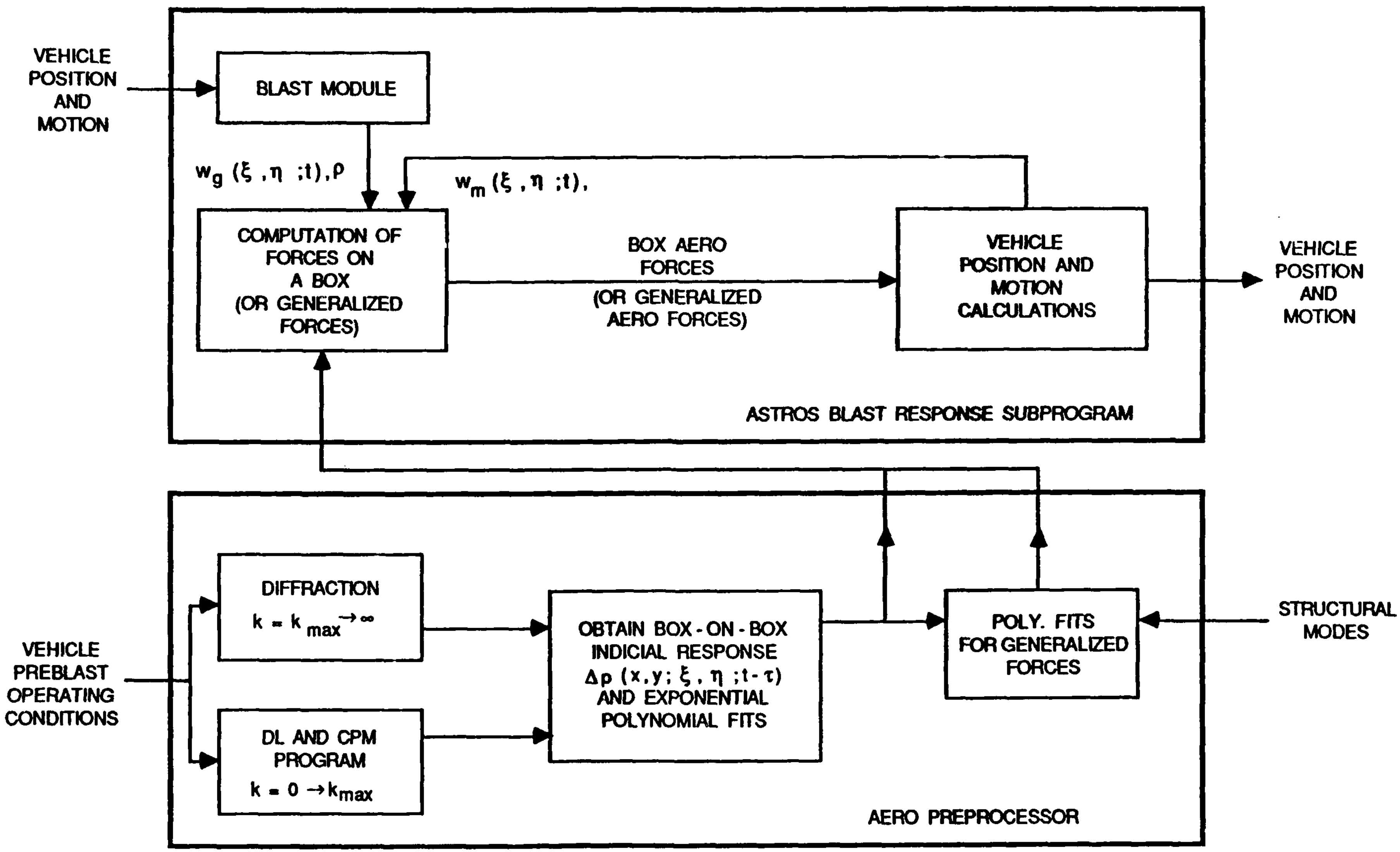
- Existing Code was a Major Resource for the New Capability

10-13-87-07-EJ

Gust Response of the Swept Wing



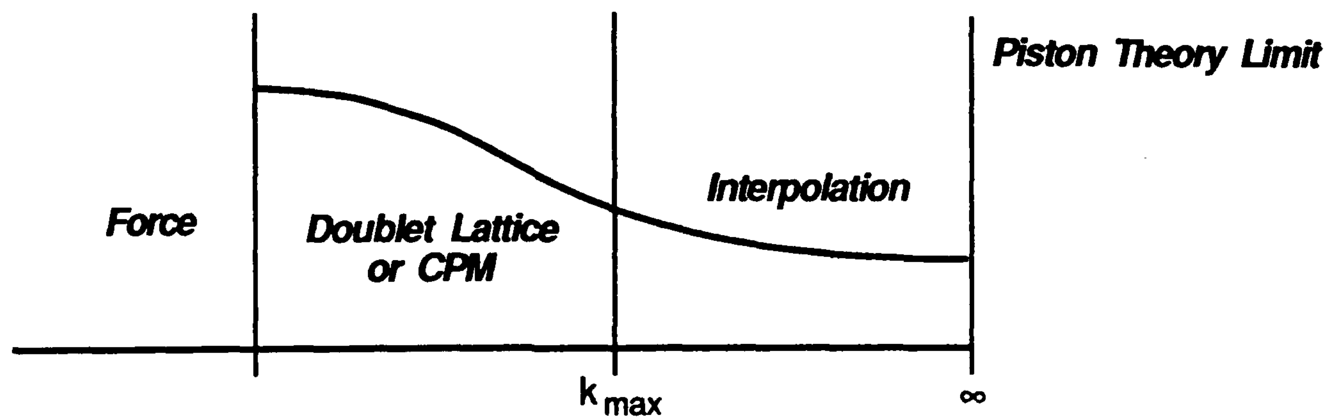
The Nuclear Blast Calculation



The Aero Preprocessor For Nuclear Blast Calculation

- The Blast Calculations are Performed in the Time Domain While Unsteady Aerodynamics are Available in the Frequency Domain

- Fourier Transform Techniques are Used to Compute Indicial Time Response From Frequency Dependent Aerodynamics



- Special Treatment is Given to the Early Time Loading of a Box on Itself

The Aero Preprocessor (Concluded)

- **Indicial Function is Fit By Decaying Exponentials**

$$F(t) = a_o + \sum_n a_n \exp(\beta_n t)$$

β_n Values are User Input

Fit is Performed at User Input Times t_m

- **Matrix Notation For Load at Time t Due to Disturbance at Time t' is**

$$[F(t,t')] = [MATSS] + \sum_{n=1}^{N} [MATTR]_n \exp(-\beta_n (t-t'))$$

- **Matrices are Converted to Generalized Form For the Response Calculation**

The Blast Response Calculation

- **A Trim Analysis is Performed to Obtain Initial Conditions**
  - Similar to Static Aeroelastic Trim Analysis
  - Modal Coordinates are Used
- **Transient Response Performed Using Newmark - Beta**
- **Gravity and Inertia Forces Included in the Calculation**
- **Aerodynamic Forces Combine Effects From**

  Blast Wave

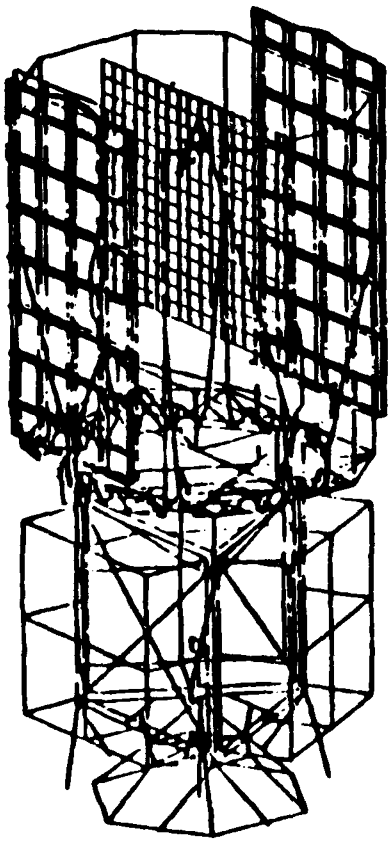
  Vehicle Translation

  Vehicle Rotation

  Vehicle Deformations
- **Matrix Equation For Aerodynamic Forces Computed Recursively**

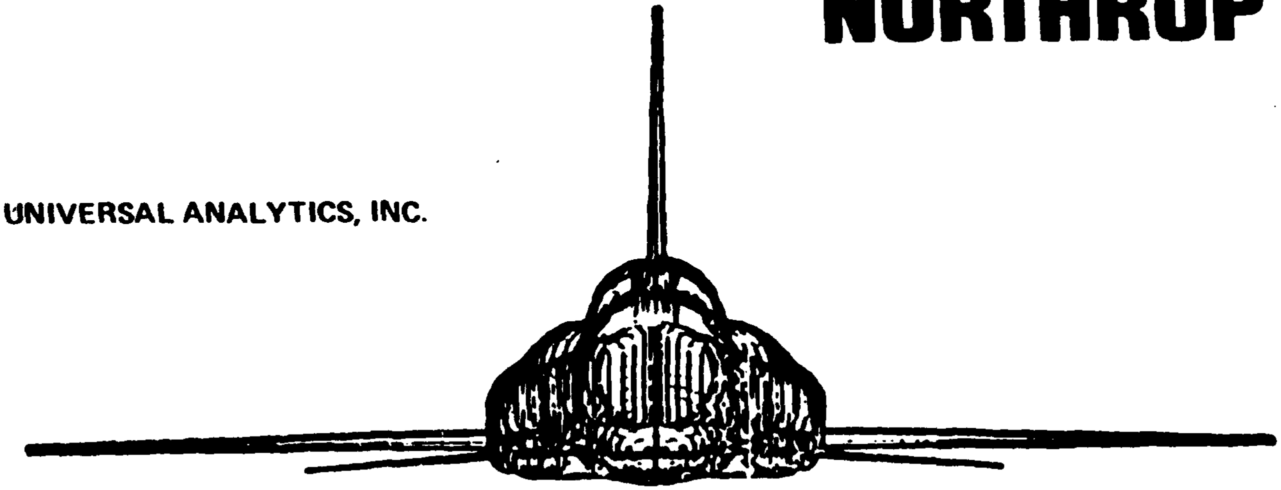
ASTROS User Training Workshop

20–24 June 1988



NORTHROP

UNIVERSAL ANALYTICS, INC.



User Interface

User's Interface to ASTROS

- Overview
- Solution Control
- Bulk Data
- Output
- Executive Control Sequence (MAPOL)
- Advanced Topics

ASTROS System Organization

- **ASTROS System Consists of Two Stand Alone Executables**
  - System Generation Program
  - ASTROS Procedure

- **SYSGEN Generates Data Needed to Form and Run ASTROS**
  - Creates a Link Between Modules and Executive
  - Forms System Data Base
  - Intended to be Run Only Once at Installation

- **ASTROS Procedure**
  - Executive System
  - Engineering Software

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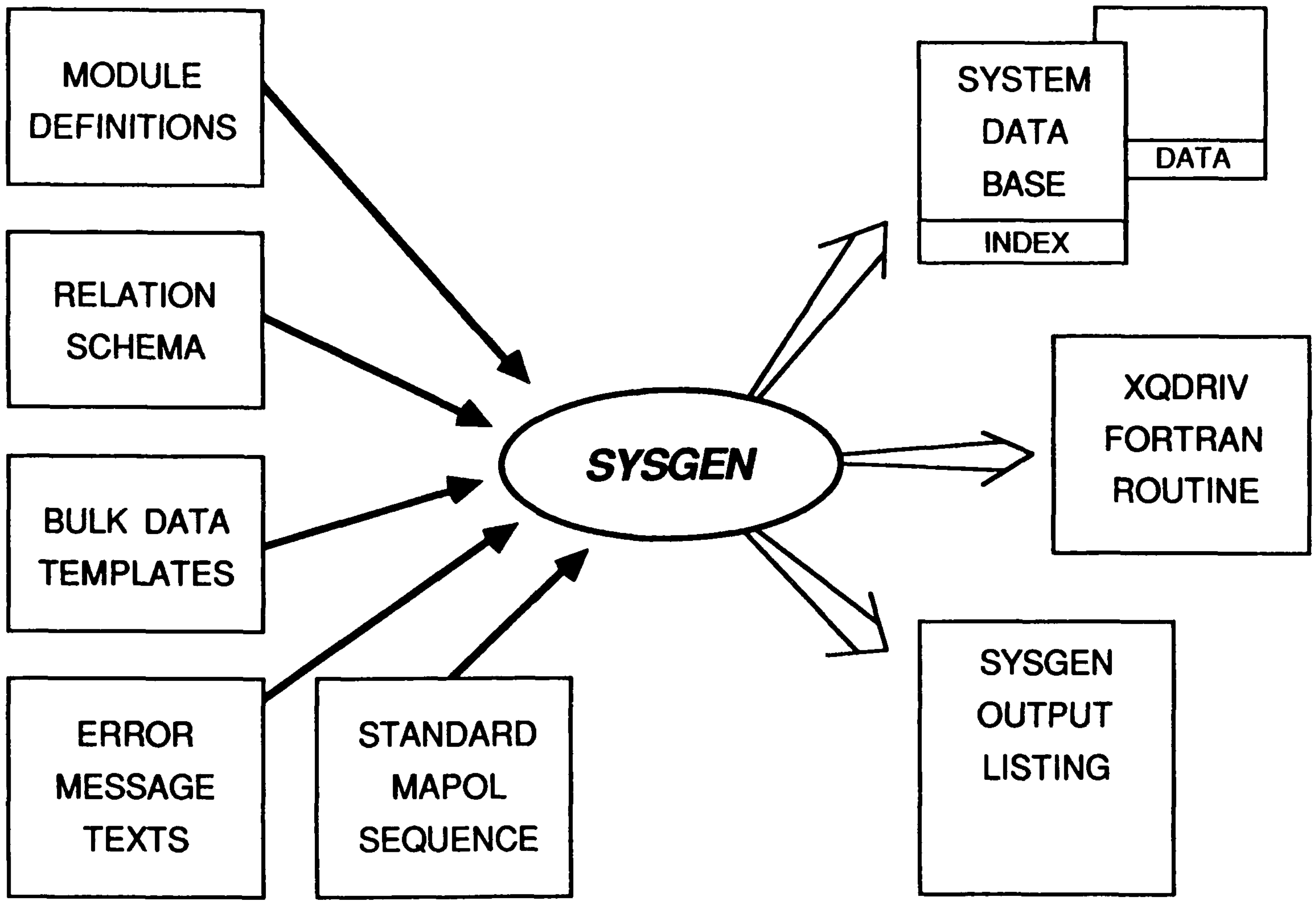
ASTROS System Generation Program, SYSGEN



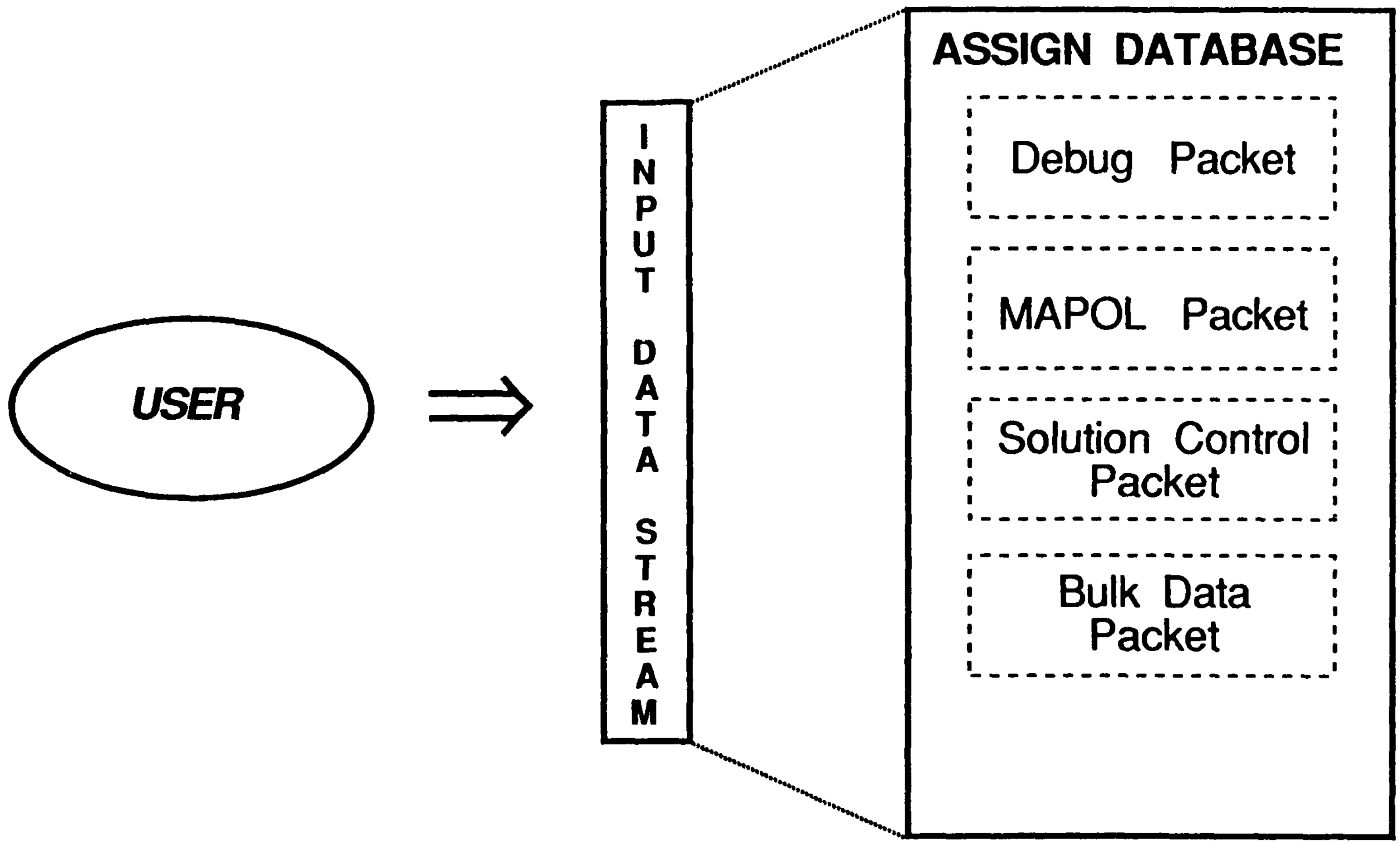
SYSGEN Output As User Documentation

- Lists Argument Types For All MAPOL Modules
- Lists Relational Schemata For " HIDDEN " Relations
- Lists the Complete Set of Bulk Data Templates
- Lists Error Message Texts and Indicates with Which " Module " They are Associated
- Provides Current Listing of the Standard MAPOL Sequence

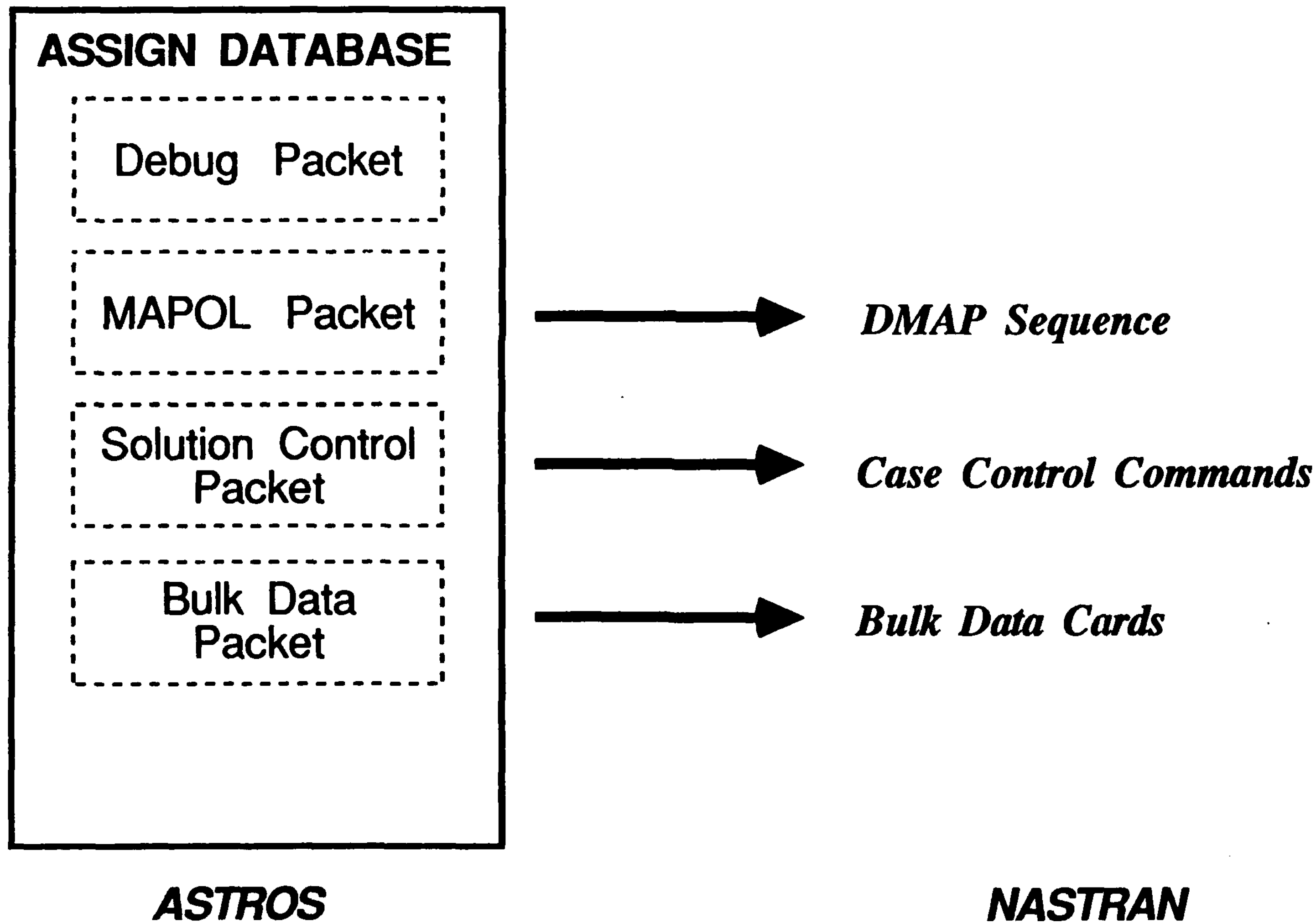
SYSGEN Output As User Documentation (Continued)

- Represents Actual Data Defining the ASTROS System
- Is More Accurate and Current Than Other Documentation
- Has More Concise Format for the Experienced User
- Can Be Made Available " On - Line "

ASTROS User Interface



Similarities Between ASTROS Input and NASTRAN Input



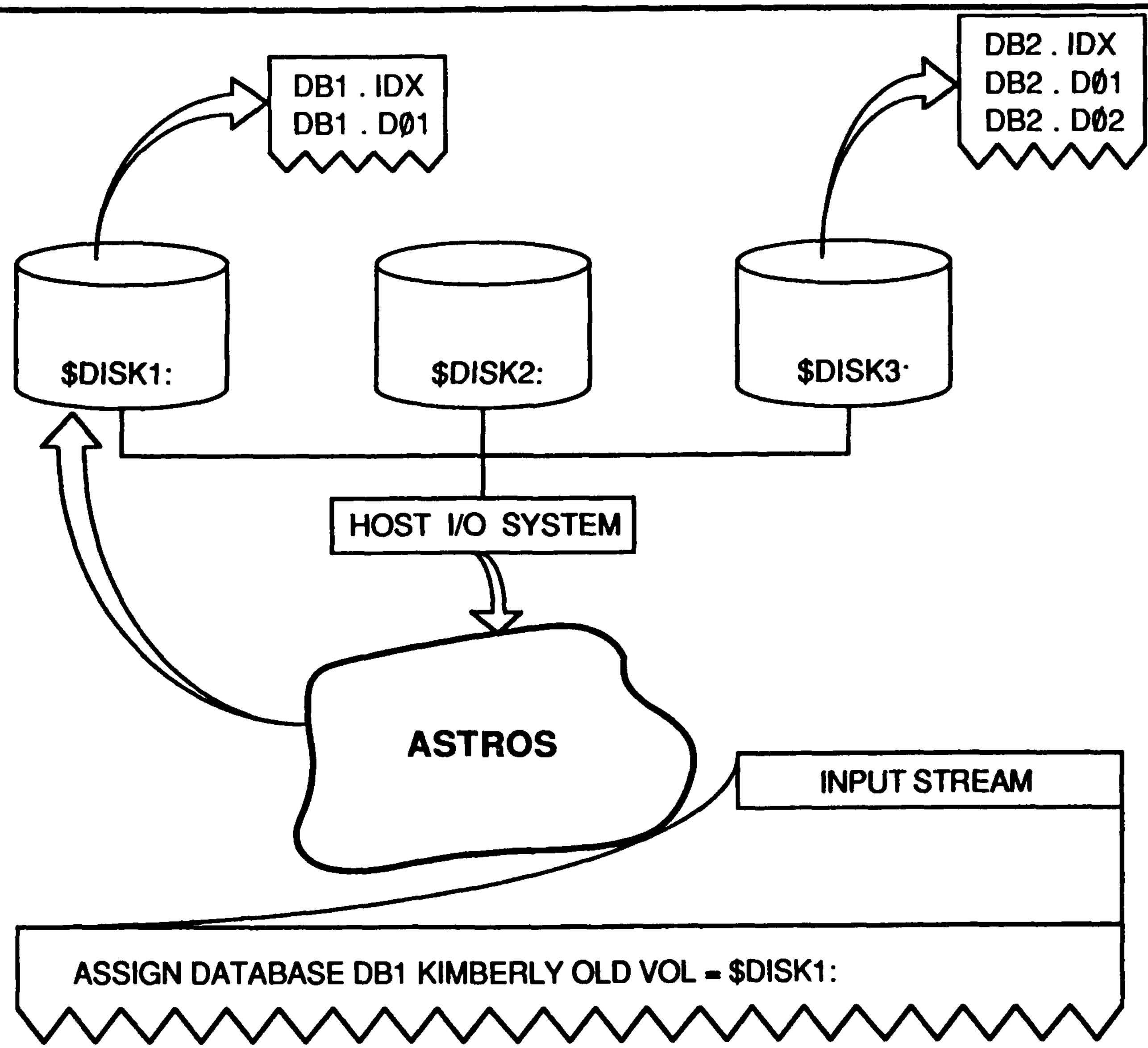
The ASSIGN DATABASE Directive

ASSIGN DATABASE <dbname> <password> <status> {params}

- dbname — is a name identifying the run time data base files (maximum of 8 characters)
- password — is a user assigned password for the data base files (maximum of 8 characters)
- status — is the status of the data base files. Must be either OLD, NEW or TEMP
- params — are optional (installation dependent) parameters e. g., DBLKSIZE = n, IBLKSIZE = n, etc.

- MUST Be the First Item in the Input Stream

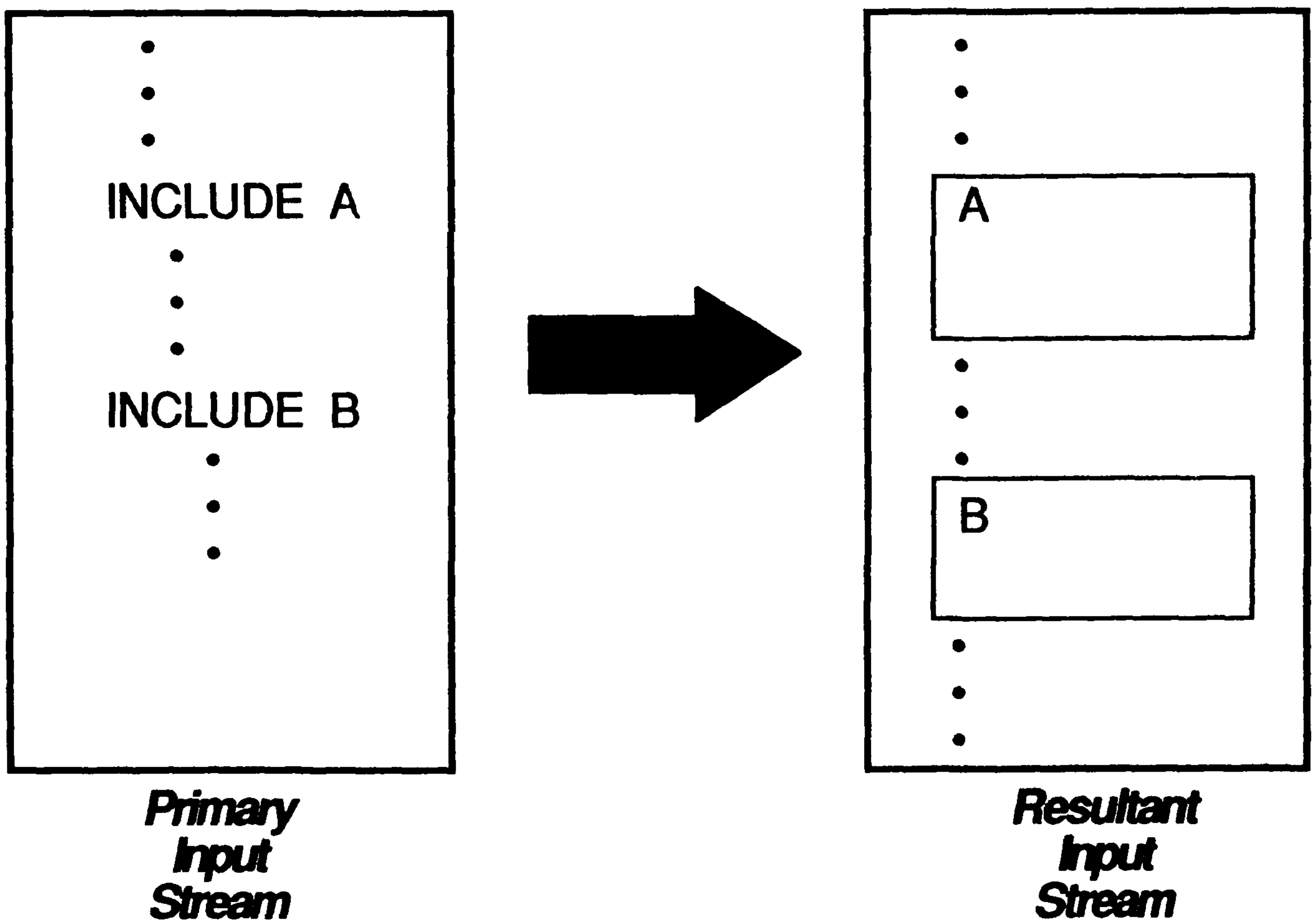
The Function of ASSIGN DATABASE Directive



The INCLUDE Directive

INCLUDE < filename >

- filename is a Host Dependent Name Used in a FORTRAN Open Statement



DEBUG Packet

- **Represents a Legitimization of a Development Feature**

- **Provides Keyword Based Requests for Specific Executive, Data Base and Engineering Debug Output :**

```
DEBUG
Key 1, Key 2 . . .
Key 3, . . .
```

- **Keywords :**

Executive	Data Base	Engineering
MSTACK	TRACE	MPYAD = n
MEXEC	EVENT	
MOBJ	BUFFER	
MTRACE	IOSTAT = { FULL, SUM }	
MATRIX	MEMORY	
	ENTITY = name	
	CALLSTAT	
	NOCOREDIR	

Solution Control Packet

- Analogous to CASE CONTROL in NASTRAN
- Selects Optimization/Analysis Tasks To Be Performed
- Selects Engineering Data for Each Task
- Selects Output Quantities

Solution Control Hierarchy

Type of Boundary Condition

Analyze Optimize

Boundary Condition

Spc	Method	K2pp	Damping
Mpc	Dynred	M2pp	Eset
Reduce	Inertia	B2pp	
Support	Tfl		

Discipline (Options)

Statics	Flutter	Blast
Modes	Transient	
Saero	Frequency	

Solution Control Contrasts Between NASTRAN and ASTROS

- Multidisciplinary Executions are Supported by ASTROS
- Boundary Conditions are More Explicitly Defined in ASTROS
- ASTROS Solution Control Enables Optimization Cases and Analysis Cases to be Independently Selected

87-IRW-009

Solution Control Boundary Condition Type

SOLUTION

```
OPTIMIZE STRATEGY = < n >
    •
    •     Optimization Subpacket
    •
                n > 999  denotes FSD
END
```

Defines Optimization Boundary Condition (s)

```
ANALYZE
    •
    •
    •      Analysis Subpacket

END
```

Defines Analysis Boundary Condition (s)

Solution Control Boundary Condition Definition

BOUNDARY < option >, {< option >, ...}

- **Matrix Reductions**

  SPC = < n >
  MPC = < n >
  REDUCE = < n > DYNRED = < n > INERTIA = < n >
  SUPPORT = < n >

- **Eigen Analysis Method**

  METHOD = < n >

- **Dynamic Matrix Assembly**

  DAMPING = < n > K2PP = < name >
  TFL = < n > B2PP = < name >
  ESET = < n > M2PP = < name >

STATICS Discipline Options

STATICS (MECHANICAL = < n >, GRAVITY = < n >, THERMAL = < n >, DCONSTRAINT = < n >)

- MECHANICAL Selects Mechanical Loads

  FORCE, MOMENT, PLOAD,
  FORCE1, MOMENT1, LOAD

- GRAVITY Selects Gravity Loads

  GRAV

- THERMAL Selects Temperature Distribution for Thermal Loads

  TEMP, TEMPD

- Each Set of Options Defines a Single Load Case as a Superposition of All Load Types

STATICS Discipline Options (Continued)

STATICS (MECHANICAL = < n >, GRAVITY = < n >, THERMAL = < n >, DCONSTRAINT = < n >)

- DCONTRAINT Selects Displacement Constraints To Be Applied to the Load Condition

  DCONDSP

- Note that Stress and/or Strain Constraints are Applied Through Bulk Data Entry DCONSTR Which is Not Selected By Solution Control

- No STATICS Options are Required But at Least One of MECH, GRAV or THERM Must Be Present

MODES Discipline Options

MODES (DCONSTRAINT = < n >)

- DCONSTRAINT Optionally Selects Modal Frequency Constraints To Be Applied to the Normal Modes

  DCONFRQ

- Note that Only One Modal Analysis May Be Performed in a Boundary Condition Using the BOUNDARY METHOD = < n > to Obtain Extraction Data

SAERO Discipline Options

SAERO (TRIM = < n >, DCONSTRAINT = < n >)

- TRIM Provides the Required Flight Configuration Information as Specified by the TRIM Bulk Data Entry
- DCONSTRAINT Optionally Selects Displacement, Aileron Effectiveness and/or Lift Effectiveness Constraints, DCONDSP, DCONALE and DCONCLA, Respectively
- Just as for STATICS, Stress and/or Strain Constraints May Be Applied Using the DCONSTR Bulk Data Entry
- SAERO Requires BOUNDARY SUPPORT = < n > to Define the Rigid Body Degrees of Freedom Appropriate to the TRIM
- SAERO Discipline Precludes the Use of Dynamic Reduction

FLUTTER Discipline Options

FLUTTER (FLCOND = < n >, DCONSTRAINT = < n >)

- FLCOND Provides the Required Flutter Parameters as Specified by the FLUTTER Bulk Data Entry
- DCONSTRAINT Optionally Selects Flutter Constraints Specified by DCONFLT Bulk Data Entries
- Flutter Analysis Requires That the Eigenvalue Extraction Method Be Specified in the Boundary Definition

TRANSIENT Discipline Options

$$\textbf{TRANSIENT} \left\{ \begin{array}{c} \textbf{MODAL} \\ \underline{\textbf{DIRECT}} \end{array} \right\} \quad \textbf{(DLOAD = <n>, TSTEP = <n>, FFT = <n>, IC = <n>, GUST = <n>)}$$

- DLOAD Specifies the Spatial and Temporal Load Components
- TSTEP Specifies the Time Steps for Response Calculations
- IC Provides Optional Initial Conditions for Direct Transient Analysis
- FFT Allows Specification for Fast Fourier Transform Methods
- GUST, Which Must Use FFT, Provides for Discrete Gust Loads But Is Not Functional

FREQUENCY Discipline Options

$$\text{FREQUENCY} \left\{ \begin{array}{c} \text{MODAL} \\ \underline{\text{DIRECT}} \end{array} \right\} \text{(DLOAD = <n>, FSTEP = <n>, GUST = <n>)}$$

- DLOAD Specifies the Spatial and Frequency Dependent Load Components
    - Note That DLOAD is Required by Solution Control Even Though It is Ignored for the GUST Option
- FSTEP Specifies the Frequency Steps for Response Calculations
- GUST Optionally Specifies the Gust Parameters for Harmonic Gust Response
- MODAL Analyses Require BOUNDARY METHOD = <n> to Perform Real Eigenanalysis

BLAST Discipline Options

BLAST $\left\{ \begin{array}{c} \underline{\textbf{MODAL}} \\ \textbf{DIRECT} \end{array} \right\}$ **(BLCOND = <n>, TSTEP = <n>)**

- BLCOND Selects the Required Nuclear Blast Parameters from the BLAST Bulk Data Entry
- TSTEP Specifies Time Steps for the Transient Response Analysis
- MODAL Analyses is the Default (Unlike Other Dynamic Response Disciplines) and the DIRECT Analysis is Not Functional
- MODAL Analyses Require BOUNDARY METHOD = <n> for Real Eigenanalysis

Combining Disciplines In A Single Boundary Condition

	STATICS	MODES	SAERO	FLUTTER	TRANSIENT	FREQUENCY	BLAST
STATICS	OK						
MODES	OK	X					
SAERO	X	X	R				
FLUTTER	OK	OK	X	OK			
TRANSIENT	OK	OK	X	OK	X		
FREQUENCY	OK	OK	X	OK	OK	X	
BLAST	OK	OK	X	OK	OK	OK	X

X - Precluded R - Allowed With Restrictions

Multidisciplinary Restrictions In ASTROS

- **Aeroelastic Correction for SAERO Discipline Precludes Any Other Discipline in the Same Boundary Condition**
- **Aeroelastic Correction Must Be Unique in a Boundary Condition so Multiple SAERO Disciplines Restricted to:**
  - Symmetric Analyses Only
  - Same Mach Number
  - Same Dynamic Pressure
- **Only One Modal Analysis Allowed in a Boundary Condition**
- **TRANSIENT, FREQUENCY and BLAST are Limited to One Analysis Each Per Boundary Condition**

Solution Control Output Requests

< PRINT / PUNCH > {(< form >)} < option > {(form)}, < subcase >, ...

- **Select Particular Response Quantities for Particular "Subcases" To Be :**
  - PRINTed to the User Output File
  - PUNCHed to the User Punch File
- **Once Selected, an Output Request Remains in Force at or Below that Level in the Hierarchy Until Overridden**

Solution Control Output Requests FORM Options

$$< \begin{matrix}\text{PRINT}\\ \text{PUNCH}\end{matrix} > \left\{\left(\frac{\text{RECTANGULAR}}{\text{POLAR}}\right)\right\} <\text{OPTION}> \left\{\left(\frac{\text{RECTANGULAR}}{\text{POLAR}}\right)\right\} \ldots.$$

- PRINT or PUNCH Form Provides a Default for the Entire Output Request
- < option > Form Overrides the PRINT / PUNCH Default Form
- RECTANGULAR Selects Real / Imaginary Parts of Complex Quantities
- POLAR Selects Magnitude / Phase of Complex Quantities
- < form > is Ignored for Real Quantities

Solution Control Output Requests: Response Quantity Options

OPTION	STAT	MODE	SAERO	FLUT	TRANS	FREQ	BLAS
PRESSURE = <n>	---	---	X	---	---	---	---
VELOCITY = <n>	---	---	---	---	X	X	X
DISPLACEMENT = <n>	X	X	X	X[1]	X	X	X
ENERGY = <n>	X	X	X	---	X	---	X
FORCE = <n>	X	X	X	---	X	---	X
GPFORCE = <n>	X	---	X	---	---	---	---
LOAD = <n>	X	---	X	---	X	X	X
SPCFORCE = <n>	X	---	X	---	---	---	---
STRESS = <n>	X	X	X	---	X	---	X
ACCELERATION = <n>	X[2]	---	X[2]	---	X	X	X
STRAIN = <n>	X	X	X	---	X	---	X
ROOT = <n>	---	X[3]	---	X[3]	---	---	---
TRIM	---	---	X	---	---	---	X

1. Flutter displacements (mode shapes) are only available for analysis and then only if a flutter crossing is found.
2. The accelerations are available for STATICS with inertia relief and all SAERO Analyses.
3. ROOTS will print real eigenvalue extraction summary data for MODES and complex eigenvalues for FLUTTER.

Solution Control Output Requests: Response Quantity Options (Cont'd)

- **Most Options Have a Subset Selection**

  Option = < n >

$$n = \left\{ \begin{array}{l} \text{ALL} \\ \text{NONE} \\ \text{Integer Set ID} \end{array} \right\}$$

- **Integer Set Identification Selects Bulk Data Entries**

  GRIDLIST

  ELEMLIST

- **TRIM is a Toggle with No Subset Selection**
- **ROOTS Subset Selection is Not Functional**

  Integer Set ID $\Leftrightarrow$ ALL

Solution Control Output Requests: Response Quality Options (Concl'd)

- DESIGN - a Toggle to Select Print of Global and Active Local Design Variables at Each Design Iteration
- DCONSTRAINT - a Toggle to Select Print of Active Constraint Values at Each Design Iteration
- Only Valid for OPTIMIZE Boundary Conditions
- Discipline Independent

Solution Control Output Requests: Subcase Options

- For All Disciplines Except STATICS and SAERO, More Than One "Subcase" is Generated By the Discipline Option
- ASTROS Requires Specific Declaration of Subcases to Which Output Requests Apply
- Absence of a Subcase Selection Implies That the Print Request Applies to NO Subcases

Solution Control Output Requests: Subcase Options (Concl'd)

- **Mode = <n> Selects Which Eigenvectors Are to Be Used to Satisfy Print Requests for MODES Discipline**

  <n> Refers to the MODELIST Bulk Data Entry

- **TIME = <n> Selects Time Steps for TRANSIENT and BLAST Disciplines**

  <n> Refers to the TIMELIST Bulk Data Entry

- **FREQ = <n> Selects Frequency Steps for FREQUENCY Discipline**

  <n> Refers to the FREQLIST Bulk Data Entry

Solution Control Output Requests: Common Pitfall

```
SOLUTION
ANALYZE
        BOUNDARY SPC = 10 , METHOD = 100

              PRINT    DISP = ALL
              STATICS  (MECH = 10)
              PRINT    MODE = 5, DISP = 5
              MODES
END
```

- A Discipline Command is Not Terminated Until Another Discipline is Encountered
- This Example Results in DISP = 5 for Both STATICS and MODES

Solution Control Output Selection: Output Labeling

TITLE - A title header that will appear as the first line on each page of output.

SUBTITLE - A secondary header that will appear on the second line of each page of output.

LABEL - A tertiary header that is typically used to identify subcase (discipline level) output.

- Similar to Their NASTRAN Counterparts

- A Confusion Can Arise When Discipline Independent Data are Labeled with the LABEL of the 1st Discipline

Solution Control Example

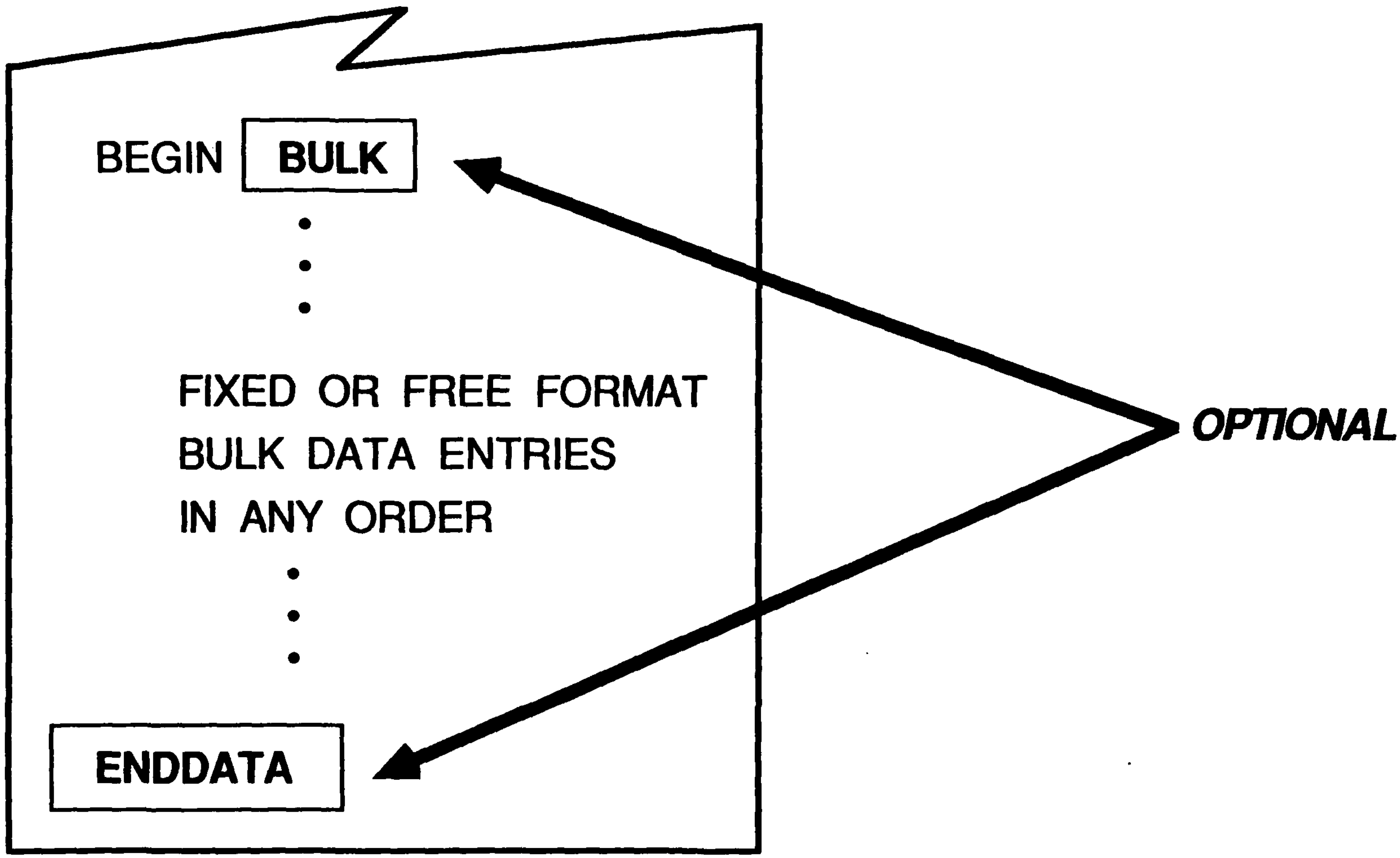
```
SOLUTION
TITLE = SWEPT WING MULTIDISCIPLINARY OPTIMIZATION
OPTIMIZE STRATEGY = 57
      PRINT DCONSTRAINT,  ROOT = ALL,  DISP = 5
      BOUNDARY        MPC = 1000, REDUCE = 1002, METHOD = 1003
            FLUTTER   ( FLCOND = 100, DCONSTRAINT = 101 )
            MODES     ( DCONSTRAINT = 200 )
            STATICS   ( MECHANICAL = 300, DCONSTRAINT = 301 )
      BOUNDARY        MPC = 2000,  SPC = 2001, REDUCE = 2002, SUPPORT = 2003
            SAERO     ( TRIM = 400, DCONSTRAINT = 401)
END
ANALYZE
      BOUNDARY        MPC = 1000, SPC = 1001, REDUCE = 1002, METHOD = 1003,
                      M2PP = MTRANS, B2PP = BTRANS, K2PP = KTRANS, ESET = 1004

            TRANSIENT MODAL (DLOAD = 500, TSTEP = 501)
            PRINT DISPLACEMENT = ALL, TIME 10, STRAIN = 12
END
```

Bulk Data Packet

- Analogous to BULK DATA Deck in NASTRAN
- Defines Structural and Aerodynamic Model Geometry
- Defines the Design Variables and Constraints
- Defines the Pool of Discipline Dependent Data for Each Analysis for Selection By Solution Control

Bulk Data Packet



Bulk Data Entry Formats

- ***Small Field Entry with a Large Field Continuation***

mnemonic	data	data	data	data	data	data	data	data	mnemonic
NAME	8	8	8	8	8	8	8	8	ABC
* BC	16		16		16		16		

- ***Large Field Entry with a Small Field Continuation***

mnemonic	data		data		data		data		mnemonic
NAME *	16		16		16		16		ABC
* BC									DEF
+ EF	8	8	8	8	8	8	8	8	

Bulk Data Entries: Fixed And Free Formats

- Each Line Must Be All Fixed or All Free Format
- Fixed Format Requires Data to Reside Within the Proper Field
- Free Format is Denoted By a Comma in the First 10 Columns; Each Field is Separated By a Comma
- Each Free Format Field Must Reside At or To the Left of Its Fixed Format Position
- Free Format Continuations May Reside on the Same Physical Line

```
MKAERO1, , 0.3, 0.5, , , , , ABC , +BC, 0.01, 0.05, 0.1, 0.2
MKAERO1, , 0.3, 0.5, , , , , 0.01, 0.05, 0.1, 0.2
```

Bulk Data Entries: Data Fields

- **Integer Data May Be Composed of Any of the Decimal Digits and an Optional Leading Plus (+) or Minus (-) Sign**

  450
  - 37
  + 45

- **Real Data Must Contain a Decimal Point But May Be Formed in Several Ways :**

  3.1
  0.0E0
  - 0.31E+1

- **Character Data May Contain Any Combination of Alphanumeric Data**

- **Blank Fields are Automatically Replaced with Ø , Ø.Ø or "   " Depending on the Field Type**

ASTROS/NASTRAN Bulk Data Format Differences

- ASTROS Continuation Lines Must Follow the Parent Entry
- ASTROS Continuation Mnemonics Need Not Be Unique
- ASTROS Free Format Does Not Allow a Blank as the Field Separator
- Real Data Containing More Characters Than the Field Size Will Not Be Rounded
- Imbedded Blanks are Not Allowed in Real or Integer Data Fields

Bulk Data Entry Differences Between ASTROS And NASTRAN

- **ASTROS Has 132 Bulk Data Entries Defined**
- **50 are Unchanged Relative to NASTRAN**
  - Static Loads
  - Boundary Condition Specification
  - Geometry
  - Material Properties
  - Unsteady Aerodynamic Model Geometry
- **41 are New for ASTROS**
  - Design Variables
  - Design Variable Linking
  - Design Constraints
  - Steady Aerodynamics Model Geometry
  - Discipline Data for New Disciplines
- **Remainder are Changed to Some Degree**

ASTROS Modifications To Existing NASTRAN Cards

- **Changes to Dynamic Loads Specification**
  - GUST
  - RLOAD1
  - RLOAD2
  - TLOAD1
  - TLOAD2
- **Multidisciplinary Analysis Changes**
  - ASET
  - ASET1
  - OMIT
  - OMIT1
  - EPOINT
  - SUPORT
  - AERO
  - MKAERO1
  - MKAERO2
  - FLUTTER
  - TRIM
- **Changes to Connectivity and Property Entries for Shape Function Design Variable Linking**
- **Other Changes**
  - DMI
  - DMIG
  - TABDMP1
  - TABLED1

Multidisciplinary Analysis Changes

Guyan Reduction, Extra Points and Support Points are All Boundary Condition Dependent

1	2	3	4	5	6	7	8	9	10
ASET	SETID	ID	C	ID	C	ID	C		
ASET	16	2	23	3516					

1	2	3	4	5	6	7	8	9	10
EPOINT	SETID	ID	ID	ID	ID	ID	ID	ID	CONT
EPOINT	1000	3	18	1	4	16	2		

CONT	ID	ID	ID	- etc -					

1	2	3	4	5	6	7	8	9	10
SUPORT	SETID	ID	C	ID	C	ID	C		
SUPORT	1000	16	215						

Multidisciplinary Analysis Changes (Continued)

Subcase Dependencies Moved to FLUTTER, MKAERO$_i$ Entries and Removed From AERO Entry

1	2	3	4	5	6	7	8	9	10
FLUTTER	SID	METHOD	DENS	MACH	VEL	MLIST	EPS		CONT
FLUTTER	19	PK	119	219	319	10	1. -4		ABC
CONT	SYMXZ	SYMXY							
+BC	1	0							

1	2	3	4	5	6	7	8	9	10
MKAERO1	SYMXZ	SYMXY	m_1	m_2	m_3	m_4	m_5	m_6	CONT
MKAERO1	1	0	0.1	0.7					+ABC
CONT	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8	
+ABC	.3	.6							

1	2	3	4	5	6	7	8	9	10
AERO	ACSID	REFC	RHOREF						
AERO	100	300.0	1.1E-7						

Multidisciplinary Analysis Changes (Concluded)

Subcase Dependencies Moved to TRIM Entry and a Subcase Independent AEROS Entry Created

1	2	3	4	5	6	7	8	9	10
TRIM	TID	MACH	QDP	SYMXZ	TRMTYP	NZ	QRATE	VO	
TRIM	1	.9	100.	1	1	1.0	0.0	0.0	

1	2	3	4	5	6	7	8	9	10
AEROS	ACSID	RCSID	REFC	REFB	REFS	GREF	REFD	REFL	
AEROS	10	20	10.	100.	1000.	1			

Shape Function Design Variable Linking Changes

- *Added Local Variable Gauge Constraint and Other Linking Data*
- *For Analysis or Optimization with Physical Linking, no Changes are Needed Relative to NASTRAN*

1	2	3	4	5	6	7	8	9	10
CBAR	EID	PID	GA	GB	X1 , GO	X2	X3	TMAX	CONT
CBAR	2	39	7	3	13				123
CONT	PA	PB	W1A	W2A	W3A	W1B	W2B	W3B	
+23		513							

1	2	3	4	5	6	7	8	9	10
PBAR	PID	MID	A	I1	I2	J	NSM	TMIN	CONT
PBAR	39	6	2.9		5.97				123
CONT	C1	C2	D1	D2	E1	E2	F1	F2	CONT
+23			2.0	4.0					
CONT	K1	K2	I12	R12	R22	ALPHA			

Direct Matrix Input - DMI and DMIG

ASTROS Data Base Requires Different Form for These Two Bulk Data Entries

1	2	3	4	5	6	7	8	9	10
DMI	NAME	PREC	FORM	M	N				CONT
DMI	TEST	RDP	REC	3	4				ABC
CONT	C1	R1	A(R1,C1)	C2	R2	A(R1,C2)	A(R1+1,C2)	C3	CONT
+BC	1	2	2.0	2	1	3.0	4.0	4	DEF
CONT	R1	A(R1,C3)	C4	R2	A(R2,C4)				
+EF	1	5.0	4	3	6.5				

1	2	3	4	5	6	7	8	9	10
DMIG	NAME	PREC	FORM						CONT
DMIG	TEST	RDP	REC						ABC
CONT	GCOL	CCOL	GROW	CROW	X_{ij}	Y_{ij}			CONT
+BC	1001	4	2001	2	1.25+5				DEF
CONT	GCOL	CCOL	GROW	CROW	X_{ij}	Y_{ij}			CONT
+EF	1001	4	3001	3	2.67+4	etc			

The Design Variable in ASTROS

$$\{t\} = [P]\{v\}$$

t - Element Properties (Local Design Variable)
v - Global Design Variable
P - Linking Matrix

There are Three Options for Specifying the Link Between Element Properties and Global Design Variables

Unique Physical Design Variable Linking

1	2	3	4	5	6	7	8	9	10
DESELM	DVID	EID	ETYPE	VMIN	VMAX	VINIT	LAYERNUM	LABEL	
DESELM	5	10	CROD	0.01	10.0	1.0			

User Label

Composite Layer Number

Initial Global Variable Value
$t_{init} = V_{init} * t_{property}$

Maximum Global Variable Value
$t_{max} = V_{max} * t_{property}$

Minimum Global Variable Value
$t_{min} = V_{min} * t_{property}$

Linked Element

Unique Global Design Variable ID

ONE ELEMENT/LAYER FOR EACH GLOBAL VARIABLE

Linked Physical Design Variable Linking

1	2	3	4	5	6	7	8	9	10
DESVAR	DVID	VMIN	VMAX	VINIT	LAYERNUM	LABEL			
DESVAR	6	0.01	2.0	1.0	13	INBDTOP			

⇕

1	2	3	4	5	6	7	8	9	10
PLIST	DVID	PTYPE	PID1	PID2	PID3	PID4	PID5	PID6	CONT
PLIST	6	PCOMP	12	14	22				

Each Property ID Links One Local Variable for Each Connected Element

Property Type
More than One PLIST May Be Used to Link Different Element Types

Connection Between DESVAR and PLIST is Made Through Matching Design Variable ID's

ONE GLOBAL VARIABLE FOR EACH LINKED ELEMENT/LAYER

Shape Function Design Variable Linking

1	2	3	4	5	6	7	8	9	10
DESVAR	DVID	VMIN	VMAX	VINIT	LAYERNUM	LABEL			
DESVAR	10	0.01	2.0	1.0	13	INBDTOP			

⇕

1	2	3	4	5	6	7	8	9	10
ELIST	DVID	ETYPE	EID1	PREF1	EID2	PREF2	EID3	PREF3	CONT
ELIST	10	CROD	12	12.0	22	1.0			

Element / P_{ref} Combinations Define the Shape

Connection Between DESVAR and ELIST is Made Through Matching Design Variable ID's

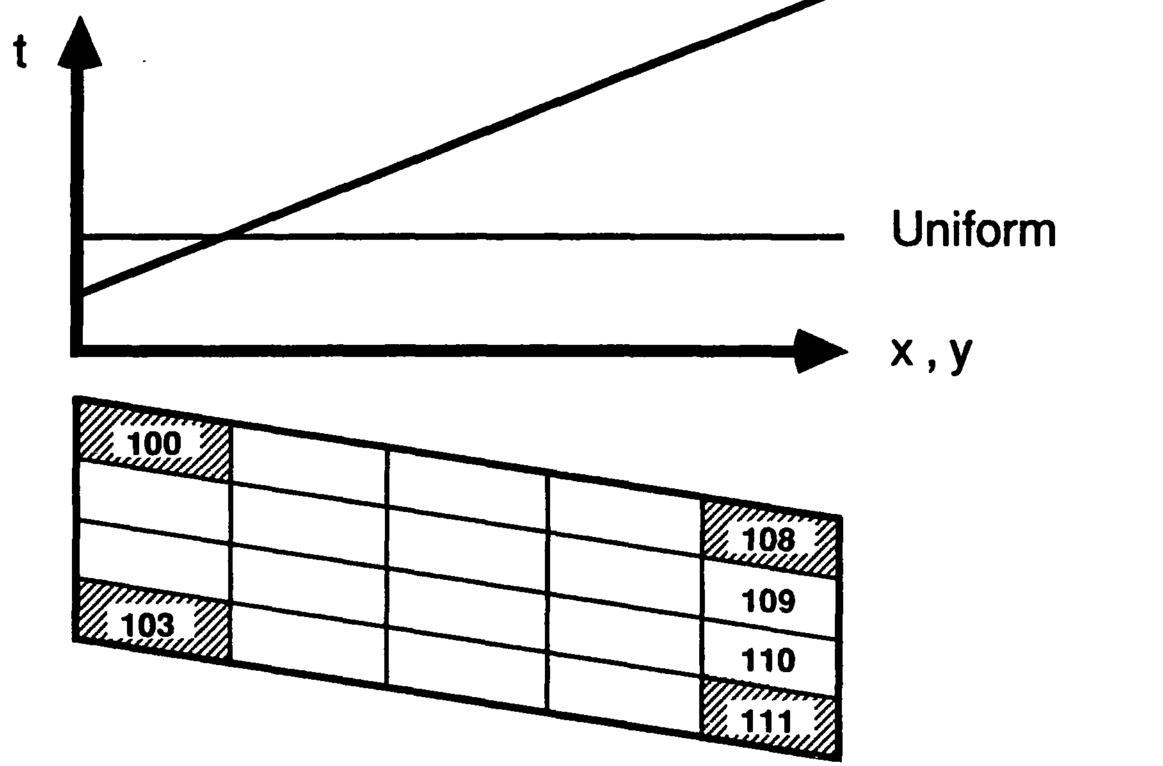
MULTIPLE ELEMENTS FOR EACH GLOBAL VARIABLE AND/OR MULTIPLE VARIABLES FOR EACH ELEMENT/LAYER

Minimum Gauge Constraints With Shape Function Linking

- Generality of Shapes Precludes the Use of Side Constraints
- Gauge Constraints are Instead Imposed as True Constraints
- The Potentially Large Number of " Active " Gauge Constraints Requires the User to Define a Subset of Elements to Control the Local Variables
- The DCONTHK Bulk Data Entry Has Been Defined for this Purpose

The DCONTHK Entry

1	2	3	4	5	6	7	8	9	10
DCONTHK	ETYPE	EID	EID	EID	EID	EID	EID	EID	CONT
DCONTHK	QDMEM1	100	103	108	111				



Design Variable Linking

- Design Variable Identification Numbers Must Be Unique Between DESVAR and DESELM Entries
- A Local Property May Only Be Linked to a Single Physical Global Design Variable
- All Designed Layers of a Composite Element Must Be Linked Using Either Physical or Shape Function Linking
- Initial Local Variable Values and Gauge Constraints are Determined from Both the Initial Property Value and Design Variable Values
- Shape Function Linking Enforces an Initially Uniform Local Property Distribution

Limitations In Design Variable Linking

- Physical Linking Should Be Allowed Through an Element List
- The Same Shape Linked to Multiple Design Variables Requires Duplicate ELIST Entries
- A Designed Composite Element is Restricted to a Single Minimum Gauge for All Layers
- Two Layers of a Composite Element Cannot Be Linked to the Same Design Variable

Design Constraints In ASTROS

	STATICS	MODES	SAERO	FLUTTER
STRESS/STRAIN	X	---	X [1]	---
DISPLACEMENT	X	---	X [1]	---
FREQUENCY	---	X	---	---
FLUTTER	---	---	---	X
AILERON EFFECTIVENESS	---	---	X [2]	---
LIFT EFFECTIVENESS	---	---	X [1]	---

1. **Symmetric Analyses Only**
2. **Antisymmetric Analyses Only**

Stress/Strain Constraint Specification

- **Constraints are Applied to Materials Via Bulk Data Entries**

- **ASTROS Automatically Generates the Proper Constraint (s) for Each Element for Each Static and Symmetric Steady Aeroelastic Analysis**

1	2	3	4	5	6	7	8	9	10
DCONSTR	MID	CRIT	MID	CRIT	MID	CRIT	MID	CRIT	
DCONSTR	1	VMISES	10	VMISES					

- **Criteria are:**

  VMISES for von Mises Stress Criterion
  TSAIWU for Tsai - Wu Strength Ratio
  STRAIN for Principal Strain Constraint

DCONSTR And The MAT1 Material Property

1	2	3	4	5	6	7	8	9	10
MAT1	MID	E	G	NU	RHO	A	TREF	GE	CONT
MAT1	17	3.+7		0.33	4.28	6.5-6	5.37-6	0.23	ABC

CONT	ST	SC	SS						
+BC	20.+4	15.+4	12.+4						

- **Only VMISES and STRAIN Constraints May Be Applied**
- **For von Mises**

  ST - Tension Stress Allowable
  SC - Compression Stress Allowable
  SS - Shear Stress Allowable

- **For Principal Strain**

  ST - Tension Strain Allowable in Microunits/Unit
  SC - Compression Strain Allowable in Microunits/Unit
  SS - Not Used

DCONSTR And The MAT2 Material Property

1	2	3	4	5	6	7	8	9	10
MAT2	MID	G11	G12	G13	G22	G23	G33	RHO	CONT
MAT2	13	6.2+3			6.2+3		5.1+3	0.056	ABC

CONT	A1	A2	A12	TO	GE	ST	SC	SS	
+BC	6.5-6	6.5-6		-500.0	0.002	20.+5	15.+5	10.+5	

- **Only VMISES and STRAIN Constraints May Be Applied**
- **For von Mises**

  ST - Tension Stress Allowable
  SC - Compression Stress Allowable
  SS - Shear Stress Allowable

- **For Principal Strain**

  ST - Tension Strain Allowable in Microunits/Unit
  SC - Compression Strain Allowable in Microunits/Unit
  SS - Not Used

DCONSTR And The MAT8 Material Property

1	2	3	4	5	6	7	8	9	10
MAT8	MID	E1	E2	NU12	G12	G1.Z	G2.Z	RHO	CONT
MAT8	171	30.+6	1.+6	0.3	2.+6	3.+6	1.5+6	0.056	+ABC
CONT	A1	A2	TREF	Xt	Xc	Yt	Yc	SS	CONT
+BC	28.-6	1.5-6	155.0	1.+4	1.5+4	2.+2	8.+2	1.+3	+DEF
CONT	Ge	F12							
+DEF	1.-4			-					

- **Only TSAIWU and STRAIN Constraints May Be Applied**
- **For Tsai - Wu**

  X_t, X_c - Tension and Compression Fiber Stress Allowable
  Y_t, Y_c - Tension and Compression Transverse Stress Allowable
  SS - Shear Stress Allowable
  F12 - Tensor Interaction Strength

- **For Principal Strain**

  X_t, X_c - Tension and Compression Strain Allowables in Microunits/Unit
  Y_t, Y_c, SS, F12 - Not Used

Additional Stress/Strain Constraint Information

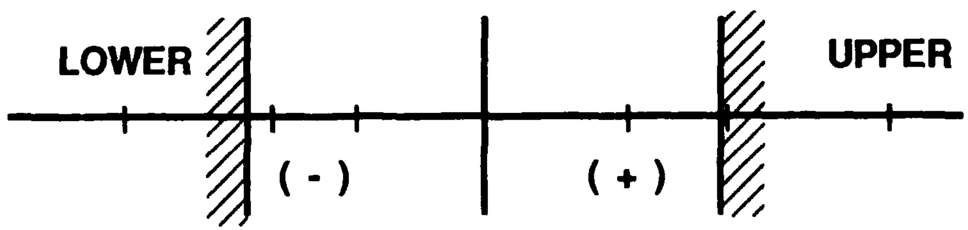
- The Isoparametric Hexahedron Elements (IHEX1 , IHEX2 , and IHEX3) Cannot Be Constrained
- The Principal Strain Constraint for the BAR Element is Not Available
- The Scalar Spring " Stress " Value May Only Be Constrained Through a Displacement Constraint
- An Element Need Not Be Designed to Be Constrained

Displacement Constraint Specification

1	2	3	4	5	6	7	8	9	10
DCONDSP	CTSET	DCID	CTYPE	DALL	LABEL	G	C	A	CONT
DCONDSP	1	10	LOWER	-2.3	TIP	32	3	2.0	ABC

CONT		G	C	A	G	C	A		etc
+BC		7	3	-4.0					

- **DCID is a Constraint ID That Must Be Unique Within Each Constraint Set**
- **All Displacement Components From a Unique Combination of CTSET / DCID Will Be Summed in the Constraint**
- **CTYPE May Be UPPER or LOWER**



Frequency Constraint Specification

1	2	3	4	5	6	7	8	9	10
DCON FRQ	SID	MODE	CTYPE	FRQALL					
DCONFRQ	3	1	LOWER	6.0					

- MODE Refers to Mode Number as Determined By the Eigenanalysis
- More Than One Constraint Can Be Applied to the Same Mode
- Cannot Use Multiple Constraints to Exclude a Frequency From a Region

Flutter Constraint Form

$$g = \frac{\gamma - \gamma_{REQ}}{GFACT} \leq 0.0$$

Where

γ - Extracted Damping Value

$$= \frac{Re\,(p)}{k} \quad \text{For Oscillatory Roots}$$

$$= \frac{p}{\ell n\, 2} \quad \text{For Real Roots}$$

γ_{REQ} - Required Damping Value Which Can Be a Function of Velocity

GFACT - Normalization Factor

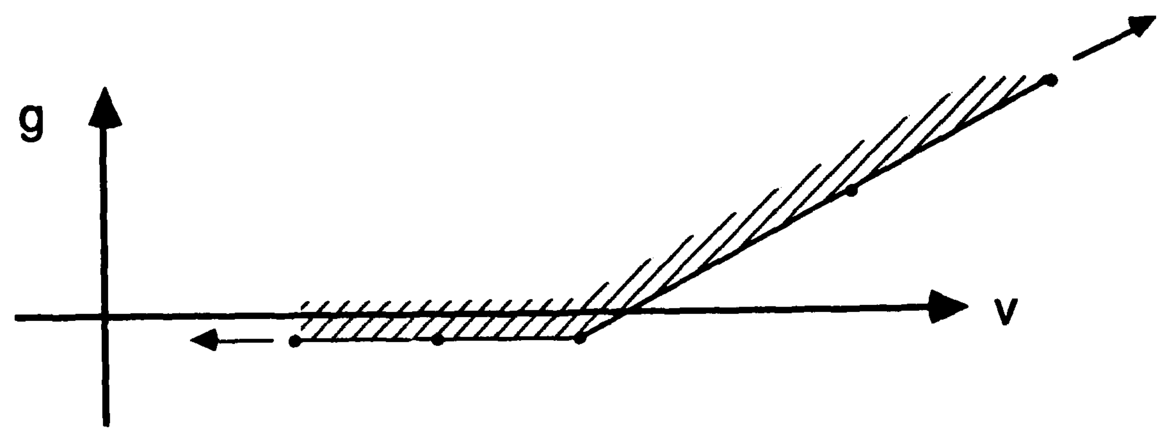
NOTE : IT IS NOT NECESSARY TO KNOW THE FLUTTER SPEED

Flutter Constraint Specification

1	2	3	4	5	6	7	8	9	10
DCONFLT	SID	GFACT	V1	GAM1	V2	GAM2	V3	GAM3	CONT
DCONFLT	2		100.0	-.01	1000.0	0.0	1500.0	0.0	+ABC

CONT	V4	GAM4	V5	- etc -					
+BC									

- GFACT is a Normalization Parameter to Make Different Constraint Types Have Similar Magnitudes; Default = 0.10
- V_i , GAM_i Specify the Constraint Boundary on a V - g Diagram



Aileron Effectiveness Constraint Specification

1	2	3	4	5	6	7	8	9	10
DCONALE	SID	CTYPE	AEREQ						
DCONALE	25	LOWER	0.4						

- May Only Be Applied to Antisymmetric Analyses
- CTYPE May Be UPPER or LOWER
- Required Effectiveness May Be Positive or Negative so That a Reversed Aileron Condition May Be Imposed

Lift Effectiveness Constraint Specification

1	2	3	4	5	6	7	8	9	10
DCONCLA	SID	CTYPE	CLAREQ						
DCONCLA	25	UPPER	0.8						

- May Only Be Applied to Symmetric Analyses of One or Two Degree of Freedom Trim
- CTYPE May Be UPPER or LOWER
- For Completeness, CLAREQ May Be Either Positive or Negative

Unsteady Aerodynamic Parameters

1	2	3	4	5	6	7	8	9	10
AERO	ACSID	REFC	RHOREF						
AERO	100	300.0	1.1E-7						

Reference Density

Reference Chord Length

Coordinate System ID

NASTRAN Has Added Fields

Velocity Field is Redundant

Symmetry Fields Limit Multidisciplinary Capability

Unsteady Aerodynamic Lifting Surfaces

1	2	3	4	5	6	7	8	9	10
CAERO1	EID	PID	CP	NSPAN	NCHORD	LSPAN	LCHORD	IGID	CONT
CAERO1	1000	1		3			2	1	ABC

Interference Group

Equal or Unequal Chordwise Cuts

Equal or Unequal Span Cuts

Coordinate System ID

Identifies Associated PAERO1 ID

Unique Element ID

+BC	X1	Y1	Z1	X12	X4	Y4	Z4	X43	
+BC	0.0								

Panel Boundaries - Edges are Parallel to the Flow

Unsteady Aerodynamic Body Connection

1	2	3	4	5	6	7	8	9	10
CAERO2	EID	PID	CP	NSB	NINT	LSB	LINT	IGID	CONT
CAERO2	1500	2	100		4	99		1	abc

Interference Group ID

Interference Body Divisions

Slender Body Divisions

Coordinate System

Associated PAERO2 ID

Unique Element ID

CONT	X1	Y1	Z1	X12					
+bc	-1.0	100	-30	175					

Body Length

Leading Point of Body

Unsteady Aerodynamic Body Properties

1	2	3	4	5	6	7	8	9	10
PAERO2	PID	ORIENT	WIDTH	AR	LRSB	LRIB	LTH1	LTH2	CONT
PAERO2	2	Z	6.0	1.0	22	91	100		ABC

- PID: ID Specified on CAERO2 Entry
- ORIENT: Type of Motion of the Body
- WIDTH: Reference Width
- AR: Heigth / Width
- LRSB: Slender Body Halfwidths
- LRIB: Interference Body Half Widths
- LTH1, LTH2: Thetas For Interference

CONT	THI1	THN1	THI2	THN2	THI3	THN3			
+BC	1	3							

- THI1 – THN3: Interference Elements Using θ_1 Array

Flutter Analysis Conditions

1	2	3	4	5	6	7	8	9	10
FLUTTER	SID	METHOD	DENS	MACH	VEL	MLIST	EPS		CONT
FLUTTER	19	PK	119	219	319	10	1.-4		ABC

- SID: Flutter ID Specified in Solution Control
- DENS: ID of Entry Defining Density Ratios
- MACH: ID of Entry Defining Mach Numbers
- VEL: ID of Entry Defining Velocities
- MLIST: List of Modes To Be Deleted From Analysis

CONT	SYMXZ	SYMXY							
+BC	1	0							

SYMXZ, SYMXY: Symmetry Flags

Multidisciplinary Analysis Requires Symmetry Condition as Part of the Specification

Bulk Data Entries For Steady Aerodynamics

FUNCTION			
CONFIGURATION	PANELING	REFERENCE DATA	TRIM
AIRFOIL	CAERO6	AEROS	TRIM
BODY	PAERO6		
AXSTA	AESURF		
AEFACT	AEFACT		

Configuration Data Provide Detailed Definition of the Aerodynamic Outline

Paneling Data Define the Mathematical Representation in USSAERO

Steady Aerodynamic Parameters

1	2	3	4	5	6	7	8	9	10
AEROS	ACSID	RCSID	REFC	REFB	REFS	GREF	REFD	REFL	
AEROS	10	20	10.	100.	1000.	1			

Reference Fuselage Length

Reference Fuselage Diameter

Reference Grid

Reference Area

Reference Span

Reference Chord

USED FOR STABILITY DERIVATIVE CALCULATIONS

Reference Coordinate System

Aerodynamic Coordinate System

NOT OPERATIONAL IN ASTROS

Airfoil Properties

1	2	3	4	5	6	7	8	9	10
AIRFOIL	ACID	CMPNT	CP	ICHORD	IUST	ILST	ICAM	RADIUS	CONT
AIRFOIL	1	WING	1	10	20		30		abc

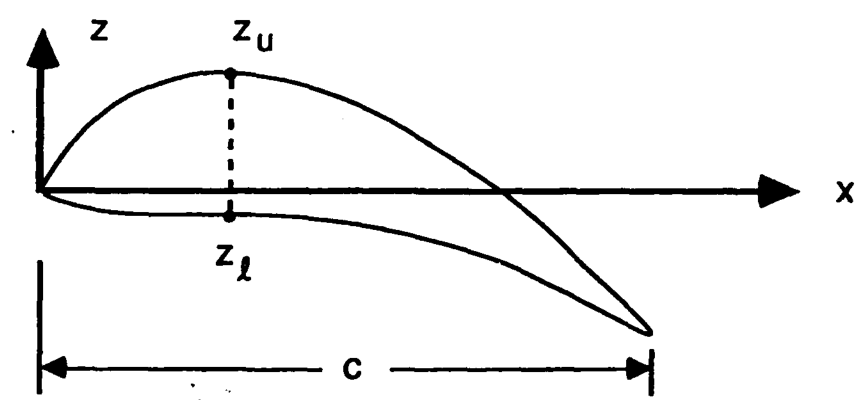
- ACID: Associated Component ID
- CMPNT: Component Type
- ICHORD: ID For Chordwise Division Points
- IUST: ID For Upper Surface Thicknesses
- ILST: ID For Lower Surface Thicknesses
- ICAM: ID For Camber Slopes
- RADIUS: Leading Edge Radius

CONT	X1	Y1	Z1	X12	IPANEL				
+BC	0.0	0.0	0.0	50.					

- X1, Y1, Z1: Leading Edge Location
- X12: Chord Length
- IPANEL: ID For Chordwise Paneling Cuts

Airfoil Properties (Concluded)

- Chordwise Divisions are Given in Percent Chord
- Thickness / Camber Data are Defined as



Upper + Lower		*Upper + Camber*	
Upper =	$100\ z_u / c$	Upper =	$100\ (z_u - z_\ell)/c$
Lower =	$-100\ z_\ell / c$	Camber =	$50\ (z_u + z_\ell)/c$

Steady Aerodynamic Lifting Surface

1	2	3	4	5	6	7	8	9	10
CAERO6	ACID	CMPNT	CP	IGRP	LCHORD	LSPAN			
CAERO6	1	WING		1	20	30			

ID of Spanwise Panel Cuts

ID of Chordwise Panel Cut

Group Number

Reference Chord

Reference Coordinate System

Chordwise Cuts are in Percent Chord

Spanwise Cuts are in Physical Coordinates

Body Properties

1	2	3	4	5	6	7	8	9	10
BODY	BCID	CMPNT	CP	NRAD	XLOC	YLOC	ZLOC		
BODY	10	FUSEL	0	3					

Leading Point of POD

Number of Equal Radial Cuts

Component Type

Component ID

Station Properties

AXSTA	BCID	XSTA	CBOD	ABOD	LYRAD	LZRAD			
AXSTA	10	10.0	0.5		10	20			

ID For Z ORDINATES

ID For Y Ordinates

Body Area

Body Camber Value

Station Location

Component ID

Steady Aerodynamic Body Surface

1	2	3	4	5	6	7	8	9	10
PAERO6	BCID	CMPNT	CP	IGRP	NRAD	LRAD	LAXIAL		
PAERO6	10	FUSEL	0	3	4				

- BCID: Component ID
- CMPNT: Component Type
- IGRP: Group ID
- NRAD: Number of Equal Radial Cuts
- LRAD: ID For Radial Cuts
- LAXIAL: ID For Axial Locations

NRAD and LRAD Cannot Both Be Non - Zero

If NRAD and LRAD are Blank, BODY or AXSTA Data are Used

If LAXIAL is Blank, AXSTA Data are Used

Limits on Configuration Data in USSAERO

PARAMETER	LIMIT	BULK DATA ENTRY	DATA FIELD	QUANTITY
NWAF	$2 \leq NWAF \leq 20$	AIRFOIL	N/A	Airfoils on the wing
NFIN & NCAN	$NFIN = 2$ $NCAN = 2$	AIRFOIL	N/A	Airfoils on canards and fins
NF	$0 \leq NF \leq 6$	CAERO6	N/A	Fins in a given group
NCAN	$0 \leq NCAN \leq 6$	CAERO6	N/A	Canards in a given group
NFUS	$NFUS \leq 6$	BODY	N/A	Fuselage segments
NP	$0 \leq NP \leq 9$	BODY	N/A	Pods
NWAFOR	$3 \leq NWAFOR \leq 30$	AIRFOIL	ICHORD	Chordwise division points to define a wing airfoil
NFINOR & NCANOR	$3 \leq NFINOR \leq 10$ $3 \leq NCANOR \leq 10$	AIRFOIL	ICHORD	Chordwise division points to define a fin or canard airfoil
NFORX	$2 \leq NFORX \leq 30$	AXSTA	N/A	Axial stations per fuselage segment
NRADX	$3 \leq NRADX \leq 20$	AXSTA/ BODY	LYRAD/ NRAD	Radial cuts for a given axial station for half the fuselage
NPODOR	$2 \leq NPODOR \leq 30$	AXSTA	N/A	Axial stations per pod
NTS	$3 \leq NTS \leq 21$	AXSTA/ BODY	N/A	Radial cuts for a given axial station for a complete pod

Limits on Paneling Data in USSAERO

PARAMETER	LIMIT	BULK DATA ENTRY	DATA FIELD	QUANTITY
NBOX	NBOX $\leq$ 600	N/A		Total number of boxes in the model
KWAF	2 $\leq$ KWAF $\leq$ 20	CAERO6	LSPAN	Spanwise division to define wing panel edges
KWAFOR	3 $\leq$ KWAFOR $\leq$ 30	CAERO6	LCHORD	Chordwise divisions to define wing panel edges
KFORX	2 $\leq$ KFORX $\leq$ 30	PAERO6	LAXIAL	Axial panel edges for a fuselage segment
KRADX	3 $\leq$ KRADX $\leq$ 20	PAERO6	LRAD	Radial panel edges for a fuselage segment
KF & KCAN	2 $\leq$ KF $\leq$ 20 2 $\leq$ KCAN $\leq$ 20	CAERO6	LSPAN	Spanwise divisions to define fin (canard) panel edges
KFINOR & KCANOR	3 $\leq$ KFINOR $\leq$ 30 3 $\leq$ KCANOR $\leq$ 30	CAERO6	LCHORD	Chordwise divisions to define fin (canard) panel edges
KPOD	3 $\leq$ KPOD $\leq$ 30	PAERO6	LAXIAL	Axial panel edges for a pod
KTRAD	3 $\leq$ KTRAD $\leq$ 21	PAERO6	LRAD	Radial panel edges per pod

Control Surface Definition

1	2	3	4	5	6	7	8	9	10
AESURF	SETID	LABEL	ACID1	CID1	FBOXID1	LBOXID1			
AESURF	600	ELEV	6000	1	6010	6030			

Last Box on the Control Surface

First Box on the Control Surface

Not Used

Component ID

Type of Control

Not Used

Flight Condition Parameters

1	2	3	4	5	6	7	8	9	10
TRIM	TID	MACH	QDP	SYMXZ	TRMTYP	NZ	QRATE	VO	
TRIM	1	.9	100.	1	1	1.0	0.0	0.0	

- VO — Velocity
- QRATE — Pitch Rate
- NZ — Load Factor
- TRMTYP — Trim Type
  - 0 No Trim
  - 1 Lift
  - 2 Lift + Pitching
- SYMXZ — Symmetry
  - 1 Symmetric
  - -1 Antisymmetric
- QDP — Dynamic Pressure
- MACH — Mach Number
- TID — TRIM ID From Solution Control

Rigid Load Transfer

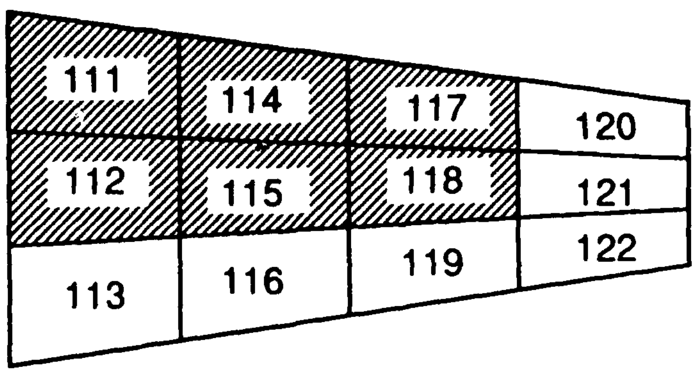
1	2	3	4	5	6	7	8	9	10
ATTACH	EID	MACROID	BOX1	BOX2	RGRID				
ATTACH	100	111	111	118	1				

Grid Point of Transfer

Last Box For Transfer

First Box For Transfer

ID of Aerodynamic Component



Sample Data Affects the Shaded Boxes

The ASTROS Input File Processor (IFP)

- An Application Module that Interprets the Bulk Data Entries Based on the Templates
- Performs Intra - Entry Error Checks as Directed on the Templates
- On Restart, <u>Appends</u> Additional Entries Onto Existing Data
- Must Be Called By the Executive for Every Execution

The ASTROS Bulk Data Template

*** GRID BULK DATA ENTRY TEMPLATE ***

GRID	ID	CP	X1	X2	X3	CD	PS			
CHAR	INT	INT	REAL	REAL	REAL	INT	INT			
DEFAULT										
CHECKS	GT 0	GE 0				GE 0	COMP			
	1	2	3	4	5	6	-7			
GRID	GRIDID	CP	X	Y	Z	CD	PERMSPC		38	$

*** EIGR BULK DATA ENTRY TEMPLATE ***

EIGR	SETID	METHOD	F1	F2	NE	ND		E	CONT	
CHAR	INT	CHAR	REAL	REAL	INT	INT		REAL	CHAR	
DEFAULT								1.E-10		
CHECKS	GT 0	RMETH	GE 0.	GEP	GE 0	GE 0		EIGE		
	1	2	4	5	6	7		8		
EIGR	SETID	METHOD	MINFREQ	MAXFREQ	ROOTEST1	ROOTDES1		ORTHPARM31		
+EIGR	NORM	G	C							
CHAR	CHAR	INT	INT							
DEFAULT	MAX									
CHECKS	NORM	EIGG	EIGC							
	9	11	-12							
	NORM	GRID1	COMPNTS1							$

User Output From ASTROS

- System Controlled Output
- Solution Controlled Output
- Executive Controlled Output

System Controlled Output From ASTROS

- Title Page and Page Headers
- Default Output From Engineering Modules
- System and User Error Messages

ASTROS System Headers

```
AUTOMATED STRUCTURAL OPTIMIZATION SYSTEM

*****  *****  *****  *****  *****  *****
*   *  *        *    *   *  *   *  *
*****  *****    *    *****  *   *  *****
*   *      *    *    *  *   *   *      *
*   *  *****    *    *   *  *****  *****

  INITIAL PRODUCTION RELEASE - VERSION 2

          DEC VAX/VMS SERIES
             JUNE 1, 1988

ASSIGN DATABASE FSW3 SHAZAM NEW DELETE
```

TITLE	ASTROS VERSION X DATE PAGE #
SUBTITLE	ASTROS ITERATION X
LABEL	RESPONSE QUANTITY LABELING

ASTROS Default Output From Engineering Modules

- Very Limited Amount to Reduce Magnitude of Output
- BDCASE / ABOUND Boundary Condition Summaries
- Active Constraint Summary
- Approximate Optimization Summary
- Final Design Data
- Termination States and Timing Summary

Boundary Condition Default Output

```
MODIFIED ACOSS II MODEL                                                    ASTROS VERSION 2
NATURAL FREQUENCY DESIGN, FIRST 2 MODES                                    ASTROS ITERATION 1

   B O U N D A R Y   C O N D I T I O N   S U M M A R Y   F O R   B O U N D A R Y   C O N D I T I O N  1


****        STATICS/NORMAL MODES          *******                  DYNAMIC RESPONSE                        ****
***                                        *****           MODAL              *****     DIRECT              ***
** STATICS MASS MODES          SAERO        *** FLUTTER   TRANS     FREQ    BLAST *** TRANS    FREQ   BLAST **
*    NO     YES  YES            NO           *    NO       NO        NO      NO    *   NO       NO     NO    *
```

```
ABOUND SUMMARY FOR BOUNDARY CONDITION   1 :

    ABC    NAU    NADSC   NADC   AFC    AAC    NAE    NMPC   NSPC   NOMIT  NRSET  NLOADS
     1      0       0      2      0      0      0      0     108     36      0      0
```

Active Constraint Summary

```
MODIFIED ACOSS II MODEL                                                          ASTROS VERSION 2
NATURAL FREQUENCY DESIGN, FIRST 2 MODES                                          ASTROS ITERATION 9

                         S U M M A R Y   O F   A C T I V E   C O N S T R A I N T S
                                 2 CONSTRAINTS RETAINED OF 2 APPLIED

                    THE APPROXIMATE OPTIMIZATION PROBLEM WAS CONVERGED WITH
                    FEASIBLE CONSTRAINT CRITERIA (CTLMIN)...:    5.00000E-04 AND
                    ACTIVE CONSTRAINT CRITERIA   (CTL)......:   -5.00000E-04

                    CURRENT MAXIMUM CONSTRAINT VALUE...:    6.48499E-04

                    TO TERMINATE                    ...:    -1.50000E-03 <    6.48499E-04 <=    1.00000E-03

                    *** ASTROS OPTIMIZATION HAS CONVERGED ***

   COUNT   CONSTRAINT VALUE    CONSTRAINT TYPE       TYPE COUNT  BOUNDARY ID  SUBCASE  ELEMENT TYPE   EID

     1      -1.45733E-04     LOWER BOUND FREQUENCY       1           1          2                      0
     2       6.48499E-04     LOWER BOUND FREQUENCY.      2           1          1                      0
```

Approximate Optimization Summary

```
****            ASTROS APPROXIMATE OPTIMIZATION                      ****
***                  SUMMARY - ITERATION  1                           ***
**                METHOD = MATH PROGRAMMING                            **
*    CURRENT       PREVIOUS      OBJECTIVE     PERCENT    CONVERGENCE   *
*   OBJECTIVE     OBJECTIVE       CHANGE       CHANGE        FLAG       *
*  3.98656E+01   4.83053E+01   -8.43971E+00   -17.472   NOT CONVERGED   *
```

Final Design Information: Iteration History

MODIFIED ACOSS II MODEL
NATURAL FREQUENCY DESIGN, FIRST 2 MODES

ASTROS VERSION 2
ASTROS ITERATION 9

A S T R O S   D E S I G N   I T E R A T I O N   H I S T O R Y

ITERATION NUMBER	OBJECTIVE FUNCTION VALUE	NUMBER FUNCTION EVAL	NUMBER GRADIENT EVAL	NUMBER RETAINED CONSTRAINTS	NUMBER ACTIVE CONSTRAINTS	NUMBER VIOLATED CONSTRAINTS	NUMBER LOWER BOUNDS	NUMBER UPPER BOUNDS	APPROXIMATE PROBLEM CONVERGENCE
1	4.83053E+01	0	0	0	0	0	0	0	NOT CONVERGED
2	3.98656E+01	38	8	2	0	0	12	45	NOT CONVERGED
3	3.13249E+01	69	7	2	1	0	0	22	NOT CONVERGED
4	2.83210E+01	152	20	2	2	0	0	24	NOT CONVERGED
5	2.74327E+01	96	17	2	2	1	0	21	NOT CONVERGED
6	2.65418E+01	82	20	2	2	0	0	7	NOT CONVERGED
7	2.66694E+01	24	6	2	2	0	0	0	CONVERGED
8	2.65104E+01	37	8	2	2	0	0	0	NOT CONVERGED
9	2.64772E+01	21	4	2	2	0	0	0	CONVERGED

THE FINAL OBJECTIVE FUNCTION VALUE IS:

FIXED =	2.90300E+01
+ DESIGNED =	2.64772E+01
TOTAL =	5.55072E+01

Final Design Information: Design Variables

A S T R O S   D E S I G N   V A R I A B L E   V A L U E S

DESIGN VARIABLE ID	DESIGN VARIABLE VALUE	MINIMUM VALUE	MAXIMUM VALUE	OBJECTIVE SENSITIVITY	LINKING OPTION	USER LABEL
1	6.99495E-02	1.00000E-02	1.00000E+03	3.25982D-01	UNIQUE PHYSICAL	
2	7.01583E-02	1.00000E-02	1.00000E+03	3.25982D-01	UNIQUE PHYSICAL	
3	1.86396E+00	1.00000E-02	1.00000E+03	5.59054D-01	UNIQUE PHYSICAL	
4	1.12259E+00	1.00000E-02	1.00000E+03	2.23622D-01	UNIQUE PHYSICAL	
5	4.33342E-02	1.00000E-02	1.00000E+03	6.02120D-01	UNIQUE PHYSICAL	
6	1.08177E+00	1.00000E-02	1.00000E+03	2.23622D-01	UNIQUE PHYSICAL	
7	4.33342E-02	1.00000E-02	1.00000E+03	6.02120D-01	UNIQUE PHYSICAL	
8	5.48568E-02	1.00000E-02	1.00000E+03	4.47243D-01	UNIQUE PHYSICAL	
9	1.80389E+00	1.00000E-02	1.00000E+03	5.59054D-01	UNIQUE PHYSICAL	
10	6.99411E-02	1.00000E-02	1.00000E+03	3.25982D-01	UNIQUE PHYSICAL	
11	7.01594E-02	1.00000E-02	1.00000E+03	3.25982D-01	UNIQUE PHYSICAL	

S U M M A R Y   O F   L O C A L   D E S I G N   V A R I A B L E S — F I N A L   R E S U L T S

R O D   E L E M E N T S

EID	LINKING OPTION	AREA	MINIMUM	MAXIMUM
1	UNIQUE PHYSICAL	6.99494660E-01	1.000E-01	1.000E+04
2	UNIQUE PHYSICAL	7.01583207E-01	1.000E-01	1.000E+04
3	UNIQUE PHYSICAL	1.86395588E+01	1.000E-01	1.000E+04
4	UNIQUE PHYSICAL	1.12259197E+01	1.000E-01	1.000E+04
5	UNIQUE PHYSICAL	4.33341980E-01	1.000E-01	1.000E+04
6	UNIQUE PHYSICAL	1.08177452E+01	1.000E-01	1.000E+04
7	UNIQUE PHYSICAL	4.33341980E-01	1.000E-01	1.000E+04
8	UNIQUE PHYSICAL	5.48567891E-01	1.000E-01	1.000E+04
9	UNIQUE PHYSICAL	1.80388851E+01	1.000E-01	1.000E+04
10	UNIQUE PHYSICAL	6.99411273E-01	1.000E-01	1.000E+04

Order Of Output For Selected Quantities

- **Discipline Quantities are Ordered for Each Boundary Condition**

    (1) Trim Parameters

    (2) Flutter Analysis Results

    (3) Applied Loads

    (4) Displacements, Velocities and/or Accelerations

    (5) Element Response Quantities Alphabetic By Element Type for:

        (a) STRESS
        (b) STRAIN
        (c) FORCE
        (d) STRAIN ENERGY

- **Design Quantities Follow All Boundary Condition Output**
- **Within Each Quantity, The Disciplines are Treated:**

(1)	STATICS	(5)	TRANSIENT
(2)	MODES	(6)	FREQUENCY
(3)	SAERO	(7)	BLAST
(4)	FLUTTER		

OFP Example - Stability Derivatives

SIMPLIFIED WING STRUCTURE DESIGN
STRESS, DISP, LIFT AND AILERON EFFECTIVENESS CONSTRAINTS
UNCONSTRAINED STABILITY DERIVATIVES

ASTROS VERSION 1.00 10/14/87
ASTROS ITERATION 1

NONDIMENSIONAL LONGITUDINAL STABILITY DERIVATIVES

MACH = 8.0000E-01 QDP = 6.5000E+00 REFERENCE GRID = 20

REFERENCE AREA = 2.4000E+03 REFERENCE CHORD = 2.0000E+01

PARAMETER	LIFT			PITCHING MOMENT		
	RIGID (DIRECT)	RIGID (SPLINED)	FLEXIBLE	RIGID (DIRECT)	RIGID (SPLINED)	FLEXIBLE
THICKNESS AND CAMBER	0.0099	0.0099	0.0174	0.0057	0.0057	0.0093
ALPHA(DEGS)	0.1173	0.1173	0.1864	-0.0062	-0.0062	0.0268
ALPHA(RADS)	6.7225	6.7224	10.6785	-0.3551	-0.3551	1.5348
ELEVATOR(DEGS)	0.0118	0.0118	0.0081	-0.0431	-0.0431	-0.0458
ELEVATOR(RADS)	0.6779	0.6779	0.4646	-2.4701	-2.4701	-2.6218
PITCH RATE(DEGS/SEC)	0.0923	0.0923	0.0830	-0.2033	-0.2033	-0.2109
PITCH RATE(RADS/SEC)	5.2904	5.2904	4.7549	-11.6503	-11.6503	-12.0849

TRIM RESULTS

ALPHA = 1.3313E+00 (DEGS) ELEVATOR = -1.3371E+00 (DEGS)

10-15-87-10-EJ

OFP Example - Stress Output

5X50 LONG, NARROW ORTHOTROPIC PLATE, W/QUAD4'S — ASTROS VERSION 1.00 10/ 6/87
QAJOB-D10410
SINE LOAD — STATICS ANALYSIS: BOUNDARY 1, SUBCASE 1

S T R E S S E S   I N   Q U A D R I L A T E R A L   P L A T E S   (Q U A D 4)

ELEMENT	LAYER	FIBER	STRESSES IN ELEMENT COORD SYSTEM			PRINCIPAL STRESSES (ZERO SHEAR)		
ID	NO.	DISTANCE	NORMAL-X	NORMAL-Y	SHEAR-XY	ANGLE	MAJOR	MINOR
1	0	5.00000E-01	1.90822E+01	2.07259E+01	-3.37227E-01	-78.8454	2.07924E+01	1.90157E+01
		-5.00000E-01	-1.90822E+01	-2.07259E+01	3.37227E-01	11.1546	-1.90157E+01	-2.07924E+01
2	0	5.00000E-01	1.72141E+01	1.86962E+01	-9.76428E-01	-63.5978	1.91809E+01	1.67294E+01
		-5.00000E-01	-1.72141E+01	-1.86962E+01	9.76428E-01	26.4022	-1.67294E+01	-1.91809E+01
3	0	5.00000E-01	1.36604E+01	1.48375E+01	-1.52206E+00	-55.5697	1.58808E+01	1.26171E+01
		-5.00000E-01	-1.36604E+01	-1.48375E+01	1.52206E+00	34.4303	-1.26171E+01	-1.58808E+01
4	0	5.00000E-01	8.77119E+00	9.52648E+00	-1.91758E+00	-50.5705	1.11032E+01	7.19443E+00
		-5.00000E-01	-8.77119E+00	-9.52648E+00	1.91758E+00	39.4295	-7.19443E+00	-1.11032E+01
5	0	5.00000E-01	3.02235E+00	3.28265E+00	-2.12568E+00	-46.7519	5.28217E+00	1.02284E+00
		-5.00000E-01	-3.02235E+00	-3.28265E+00	2.12568E+00	43.2481	-1.02284E+00	-5.28217E+00
7	0	5.00000E-01	1.58623E+01	1.30028E+01	-8.27571E-01	-15.0318	1.60845E+01	1.27806E+01
		-5.00000E-01	-1.58623E+01	-1.30028E+01	8.27571E-01	74.9682	-1.27806E+01	-1.60845E+01
8	0	5.00000E-01	1.43088E+01	1.17305E+01	-2.39648E+00	-30.8613	1.57409E+01	1.02985E+01
		-5.00000E-01	-1.43088E+01	-1.17305E+01	2.39648E+00	59.1387	-1.02985E+01	-1.57409E+01
9	0	5.00000E-01	1.13556E+01	9.30926E+00	-3.73425E+00	-37.3385	1.42043E+01	6.46056E+00
		-5.00000E-01	-1.13556E+01	-9.30926E+00	3.73425E+00	52.6615	-6.46056E+00	-1.42043E+01
10	0	5.00000E-01	7.29094E+00	5.97671E+00	-4.70479E+00	-41.0245	1.13843E+01	1.88338E+00
		-5.00000E-01	-7.29094E+00	-5.97671E+00	4.70479E+00	48.9755	-1.88338E+00	-1.13843E+01

System And User Error Messages

- Application Modules and Some Executive Routines Use Common Error Message Utility
  - Data Base
  - MAPOL Compiler
  - Solution Control
  - Some Large Matrix Utilities
- 4 Levels of " Standard " Error Message
  - (1) System Fatal
  - (2) User Information
  - (3) User Warning
  - (4) User Fatal

Determining The Source Of An Error

- **Message Text is Verbose**
- **Message Number is Included in Standard Message**

```
*** USER WARNING MESSAGE ***        NUMBER 1.17.3
INVALID DATA IN FIELD " DVID ."
DESELM  DVID   EID    ETYPE   VMIN    VMAX    VINIT   LAYRNUM LABEL
DESELM  -11    1      CROD    0.01            1.0
```

- **Data Base Errors Give Associated Entity and Attempted Action**

```
***DATABASE FATAL ERROR REPOS 05 ENCOUNTERED
***INTERFACE ROUTINE IS REPOS
***CURRENT ENTITY NAME IS PROJINDX

***THE REQUEST ATTRIBUTE VALUE IN A RELATIONAL POSITION CALL DOES NOT EXIST IN THE RELATION
***DUMP OF DATA BASE TABLES AT TIME OF ERROR
***DUMP OF MEMORY MANAGER BLOCKS
```

POINTER	NAME	GROUP	PREV	NEXT	ASIZE	USIZE	FIRSTWRD
0	***FREE****		-1	769850	769844		
769850	RELINDEX		0	770368	512	DBBLK	
770368	PGMTST		769850	770886	512	DBBLK	
770886	RELSCHEM		770368	772940	2048	DBBLK	

Executive Controlled Output

- **Optional Print Arguments on Application Modules**
  - Input Processor, IFP
  - Aerodynamics Processors, PFAERO and AMP
  - Flutter Analysis Module, FLUTTRAN
  - Stress Constraint Evaluation Module, SCEVAL
  - Design Module, DESIGN
- **Executive Print Utilities**
  - Structural Set Definition Print Utility
  - Structural Matrix Print Utility
  - General Matrix Print Utility
  - General Relational Print Utility
  - General Unstructured Entity Print Utility

Optional Print Arguments For IFP

CALL IFP (GSIZE, Sort, Echo)

Sort

= 0	Any Echo is Sorted (Default)
> 0	Any Echo is Unsorted

Echo

= 0	Echo to Output File (Default)
= 1	No Echo
= 2	Echo Only to Punch File
> 2	Echo to Both Output and Punch Files

Optional Print Argument For DESIGN

CALL DESIGN (CONVERGE, MOVLIM, CNVRGLIM, CTL, CTLMIN, OPSTRAT, NUMOPTBC, [AMAT] , print) ;

PRINT	ACTION
0	*No output is generated*
1	Initial design information and final results
2	The above and function values at each iteration
3	The above and internal MicroDOT parameters

⋮

- Only Internal Labeling is Used
- Order of Constraints May Not Match Other ASTROS Output
- Internal Scaling Further Modifies the Output

ASTROS Executive System

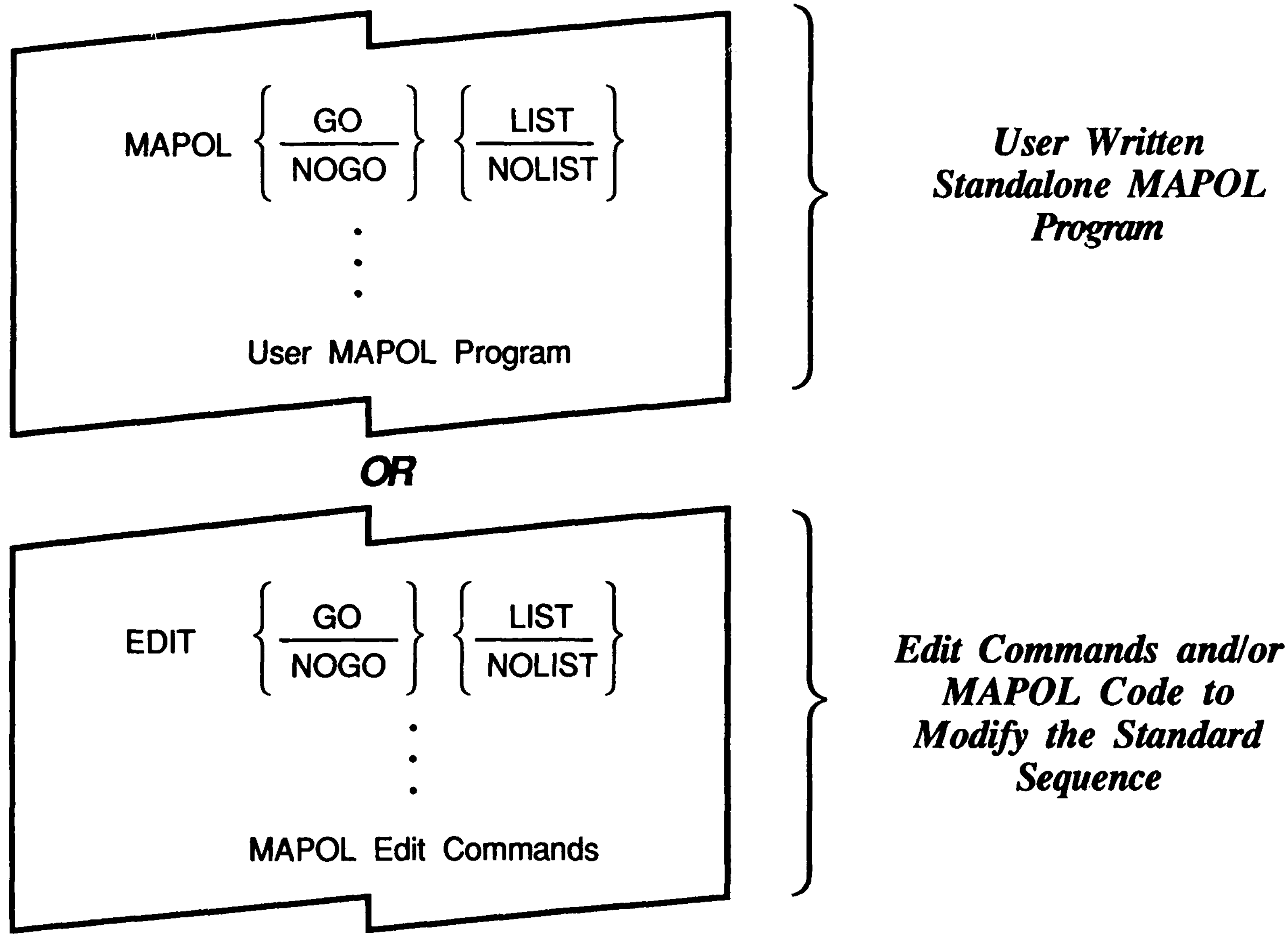
- Execution is Directed by the High Level Language MAPOL
  - Similar Role to that Played by DMAP in NASTRAN
  - Has Syntax Similar to a Scientific Programming Language

- A Single Standard Sequence is Defined During System Generation

- The Standard Sequence can be Edited or Replaced at Execution Based on Directives in the Input Stream

10-15-87-05-EJ

The MAPOL Packet



The Standard MAPOL Sequence

- 1500 Line MAPOL Program
- Supports All the Features in ASTROS
- Carefully Documented
  - Highly Structured
  - In - Line Comments
  - Detailed Documentation in Appendix C of the User's Manual

Structure Of The Standard MAPOL Sequence

OPTIMIZATION SEGMENT

ANALYSIS PHASE

```
For Each Boundary Condition Do
  Discipline 1
    Subcase 1 ———→ Constraints
    Subcase 2 ———→ Constraints
      •
   Discipline 2
     •
End Do
```

SENSITIVITY PHASE

```
Select Active Constraints
For each Active Boundary Condition Do
  Active Discipline 1
    Active Subcase 1 ——→ Constraint Sensitivities
    Active Subcase 2 ——→ Constraint Sensitivities
      •
  Active Discipline 2
      •
End Do
```

OPTIMIZATION PHASE

```
Re-Design Based on Current Active Constraints
and Constraint Sensitivities
```

FINAL ANALYSIS SEGMENT

```
For Each Boundary Condition Do
  Discipline 1
    Subcase 1
      •
   Discipline 2
     •
End Do
```

Features Of The MAPOL Language

- **Data Type Declarations**

  INTEGER
  REAL
  COMPLEX
  LOGICAL
  LABEL

  MATRIX , IMATRIX
  RELATION
  UNSTRUCT , IUNSTRUCT

- **Arithmetic Expressions, Logical Expressions, Relational Expressions**

  + , - , * , / , **
  NOT , AND , OR , XOR
  = , <> , > , >= , < , <=

- **Control STATEMENTS**

  GOTO
  FOR . . . . DO
  WHILE . . . DO
  IF . . . THEN . . . ELSE

Features Of The MAPOL Language (Concluded)

- **In-Line Procedures and Functions Analogous to FORTRAN Subroutines and Functions**

- **Intrinsic Functions**
  - Mathematical
    - SIN , COS , LN , MAX . . . .
  - Relational
    - RELUSE , RELADD , RELEND . . . .
  - General
    - EXIT
    - TRNSPOSE

User Supplied MAPOL Program Example

```
MAPOL NOLIST
$                                                                        $
$        SPECIAL MAPOL SEQUENCE FOR GENERALIZED AERO DATA                $
$                                                                        $
INTEGER  GSIZE,         NUMOPTBC,       NBNDCOND,        OPSTRAT,   MINDEX,
         NAERO;
MATRIX   [AICMAT(2)], [AAICMAT(2)],  [AIRFRC(2)],     [GTKG],    [GSTKG],
         [UGTKG],       [AJJTL],        [D1JK],          [D2JK],    [SKJ],
         [FORC],        [PHIKH],        [QHHL],          [DELCP],   [AJJDC],
         [QKKL],        [QKJL],         [QJJL];
$                                                                        $
$               BEGIN MAPOL SOLUTION SEQUENCE                            $
$                                                                        $
CALL SOLUTION( NUMOPTBC , NBNDCOND,  OPSTRAT );
CALL IFP ( GSIZE, 1 );
$                                                                        $
$        PRINT OUT THE DIRECT MATRIX INPUT PHIKH                         $
$                                                                        $
CALL UTMPRT ( , [PHIKH] );
$                                                                        $
$           GENERATE THE AIC MATRIX AND THE                              $
$           SPLINE TRANSFORMATION MATRICES                               $
$                                                                        $
CALL PFAERO ( GSIZE, [AICMAT(MINDEX)], [AAICMAT(MINDEX)],
              [AIRFRC(MINDEX)], MINDEX, NAERO, [GTKG],
              [GSTKG], [UGTKG], [AJJTL], [D1JK], [D2JK], [SKJ], [AJJDC] );
CALL AMP    ( [AJJTL], [D1JK], [D2JK], [SKJ], [QKKL], [QKJL], [QJJL] );
$                                                                        $
$           COMPUTE THE GENERALIZED AERO FROM DMI AND AICS               $
$                                                                        $
[FORC]    := [QKKL] * [PHIKH];
[QHHL]    := TRANS ( [PHIKH] ) * [FORC];
[DELCP]   := [AJJDC] * [PHIKH];
CALL UTMPRT ( , [FORC], [DELCP], [QHHL]);
END;
```

Modifying The Standard MAPOL Sequence

- 3 Commands are Available

```
INSERT   a
DELETE   a {, b}
REPLACE  a {, b}
```

- Line Numbers a and b Refer to Those in the SYSGEN Output Listing of the Standard Sequence
- No Abbreviations are Allowed in Edit Command Names
- Editing Must Be Done in Increasing Line Number Order

ASTROS Executive Sequence - User Interface

- **Typical Changes to the Standard Sequence**
  - Splitting Execution Into Separate Initialization/Looping Phases ("Restart")
  - Modification of Optimization Parameters
    - *Maximum Number of Iterations*
    - Move Limits
    - Convergence Criteria
    - Constraint Deletion Parameters
  - Modification of Print Levels in Engineering Modules
- **Typical Replacements to Standard Sequence Involve :**
  - Restart to Compute and Print Additional Data
  - Special Purpose Analyses

ASTROS User Training Workshop

20-24 June 1988

The ASTROS Executive System and Database Manager

David L. Herendeen

Universal Analytics, Inc.

Outline of Presentation

- Background
- Design Goals
- Views of the ASTROS System
- The System Design
  - The CADDB Database
  - The ASTROS "Machine"
  - The Execution Subsystem
- Conclusions

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ASTROS SOFTWARE DESIGN

BACKGROUND - LESSONS FROM OTHER SOFTWARE SYSTEMS

- NASTRAN
- IPAD
- SECOND GENERATION HELICOPTER ANALYSIS

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ASTROS SOFTWARE DESIGN

ASTROS DESIGN GOALS

- CORRECTNESS AND RELIABILITY
- COST-EFFECTIVE MAINTENANCE/ENHANCEMENT
- EFFICIENT COMPUTER RESOURCE UTILIZATION
- SIMPLIFIED USER INTERFACE
- PORTABILITY TO NEW COMPUTERS
- COMPREHENSIVE AND USABLE DOCUMENTATION

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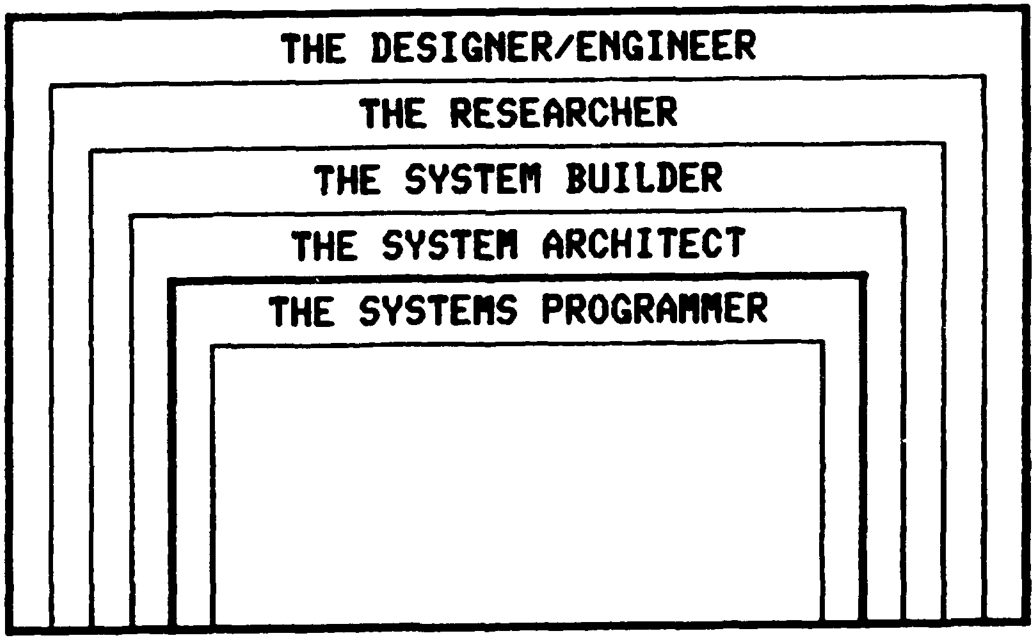
ASTROS SOFTWARE DESIGN

VIEWS OF THE ASTROS SYSTEM



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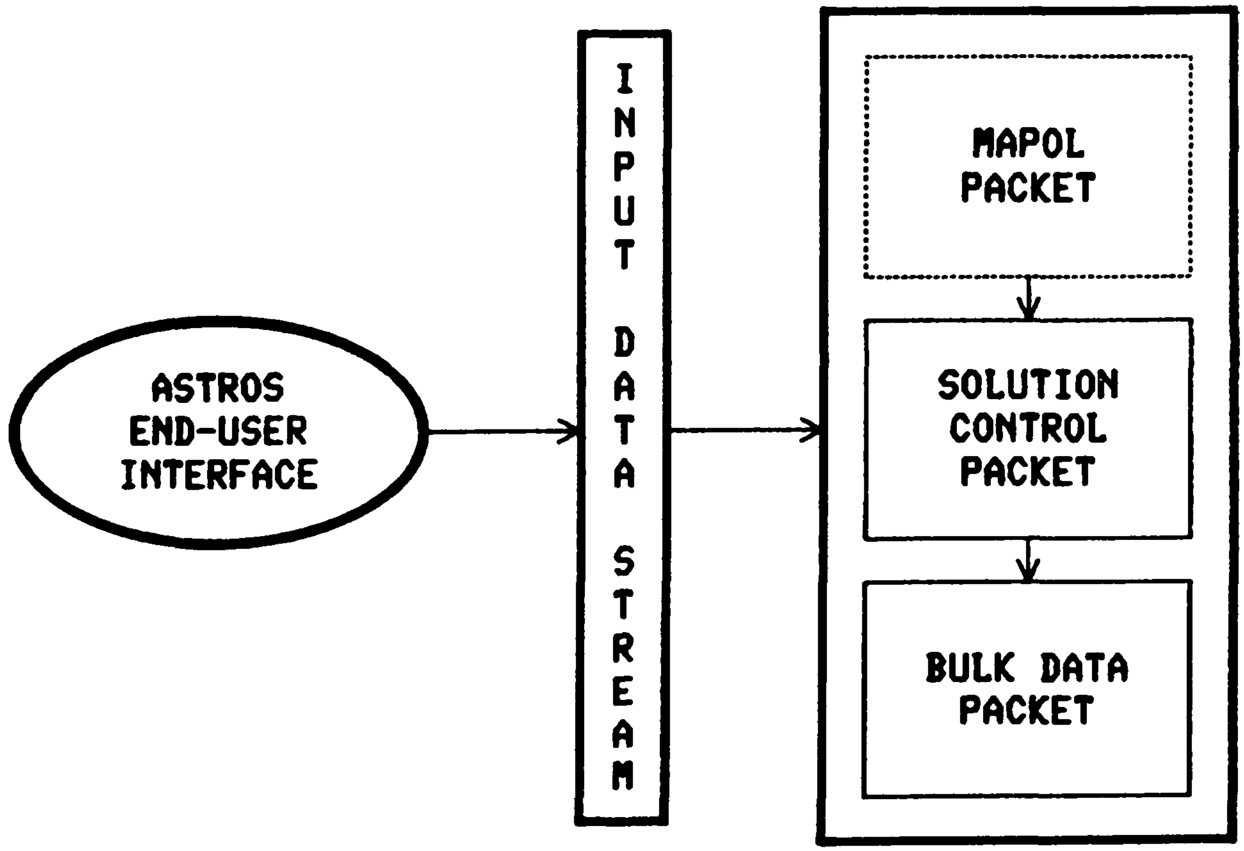
ASTROS SOFTWARE DESIGN



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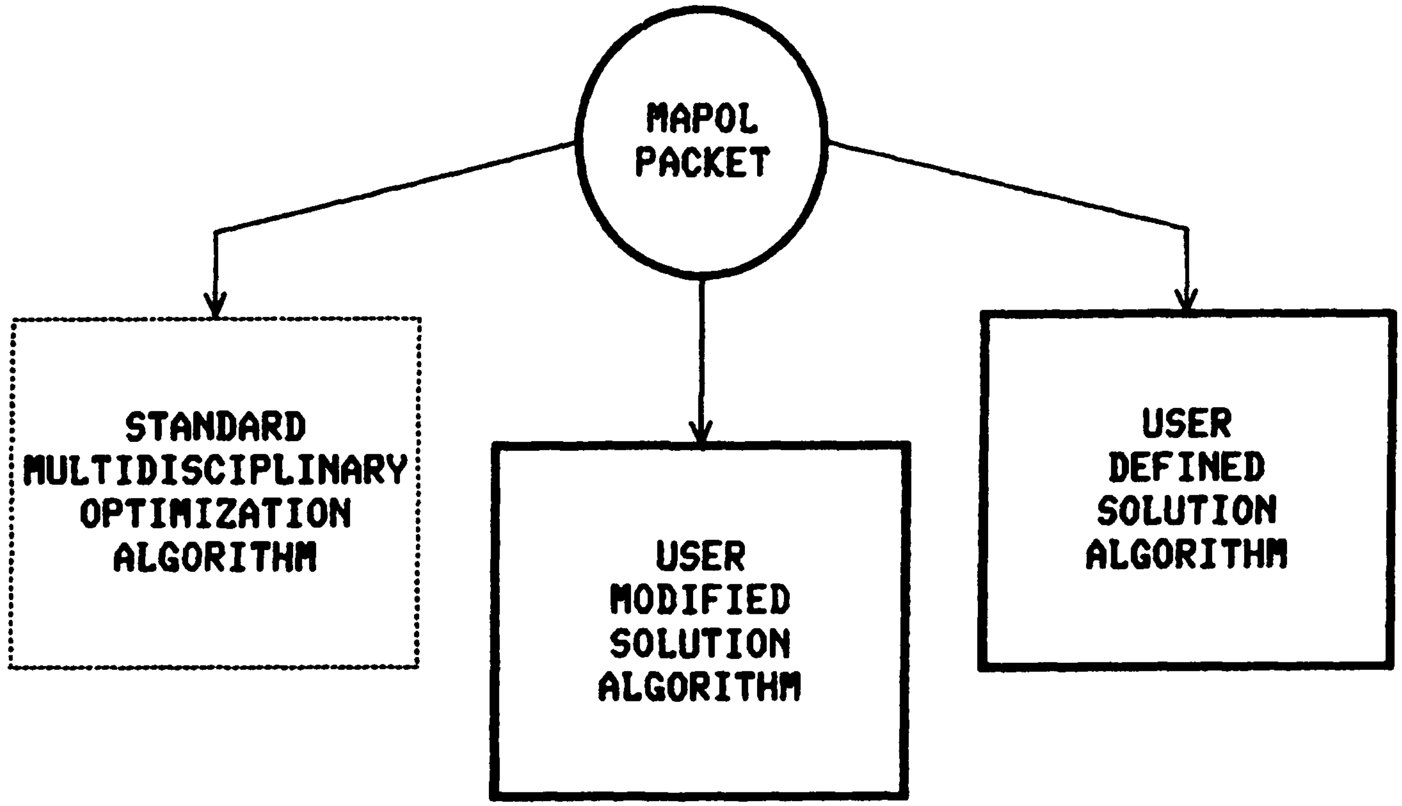
ASTROS SOFTWARE DESIGN



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ASTROS SOFTWARE DESIGN

MAPOL CODE SEGMENT FROM STANDARD SOLUTION ALGORITHM

```
$*****************************************************************

     ELIMINATE RIGID-BODY SUPPORTS

*****************************************************************$
     IF SUPPORT<>0 THEN
        CALL PARTN( [KAA],[KLR],, [KLL],[PALR] );
        IF MASS<>0 CALL PARTN( [MAA],[MLR],,[MLL],[PALR] );
        IF LOAD<>0 CALL ROWPART( [SLA],[SLL],[SLR],[PALR] );
     ELSE
        [KLL] := [KAA];
        IF MASS<>0 [MLL] := [MAA];
        IF LOAD<>0 [SLL] := [SLA];
     ENDIF;
```

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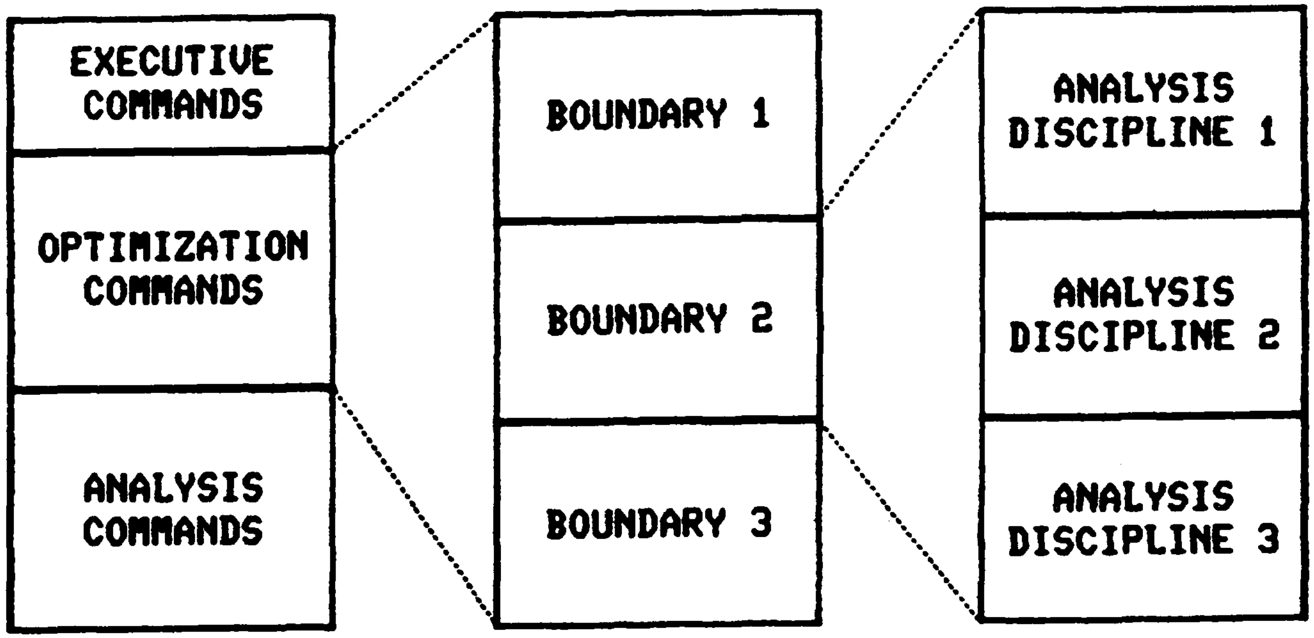
ASTROS SOFTWARE DESIGN

STRUCTURE OF SOLUTION CONTROL



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ASTROS SOFTWARE DESIGN

SAMPLE SOLUTION CONTROL SEGMENT

```
TITLE = OPTIMIZATION AND ANALYSIS OF STRUCTURE
ASSIGN DATABASE NAME=MYDATA,PASS=DLH,NEW,M.D. DATA
ASSIGN FORM(1) M.D. DATA FOR FILE 1
ASSIGN BINA(2) M.D. DATA FOR FILE 2
OPTIMIZE STRATEGY=999
SUBT = OPTIMIZATION PHASE
  BOUNDARY SPC=10
    STATICS
      LOAD  MECH=10,THERMAL=20
        LABEL = FIRST B.C. STATIC LOAD = 10
        PRINT  DISP=10,STRESS=20
      LOAD  MECH=10,GRAV=99
        LABEL = FIRST B.C. STATIC LOAD = 20
        PRINT DISP=20
        WRITE FORM(1)  DISP=50,STRESS=90
  BOUNDARY MPC=51,SPC=52,REDUCE=53,SUPPORT=54
    STATICS
      LOAD  MECH=40,ENFORCED=77
        LABEL = SECOND B.C. STATIC LOAD = 10
      LOAD  MECH=40
        LABEL = SECOND B.C. STATIC LOAD = 40
END
```

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THE ASTROS

COMPUTER AUTOMATED DESIGN DATA BASE

CADDB

ASTROS SOFTWARE DESIGN

DATA HANDLING REQUIREMENTS

- FAST ACCESS TO AND MODIFICATION OF SPECIFIC DATA ITEMS WITHIN LARGE TABLES OF RELATED INFORMATION WITH A WELL-DEFINED STRUCTURE.
- EFFICIENT STORAGE AND MANIPULATION OF LARGE (NOT NECESSARILY) SPARSE MATRICES USED IN MATHEMATICAL COMPUTATIONS.
- LARGE HETEROGENEOUS COLLECTIONS OF VARIABLE LENGTH LOOSELY STRUCTURED DATA.

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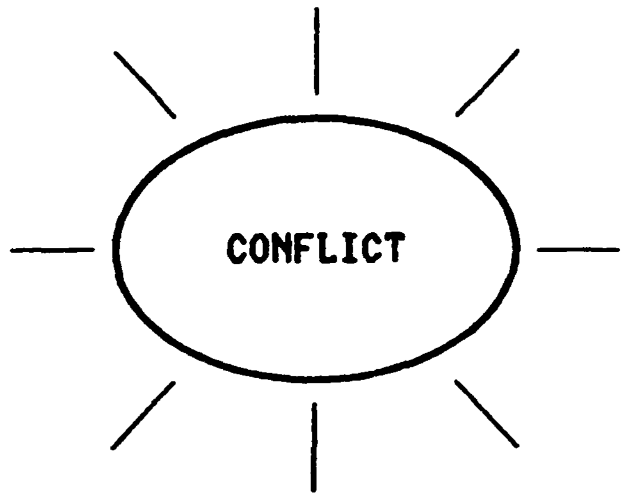
ASTROS SOFTWARE DESIGN



THERE IS NO AVAILABLE DATA BASE THAT SATISFIES THESE REQUIREMENTS WITH A MODICUM OF EFFICIENCY!

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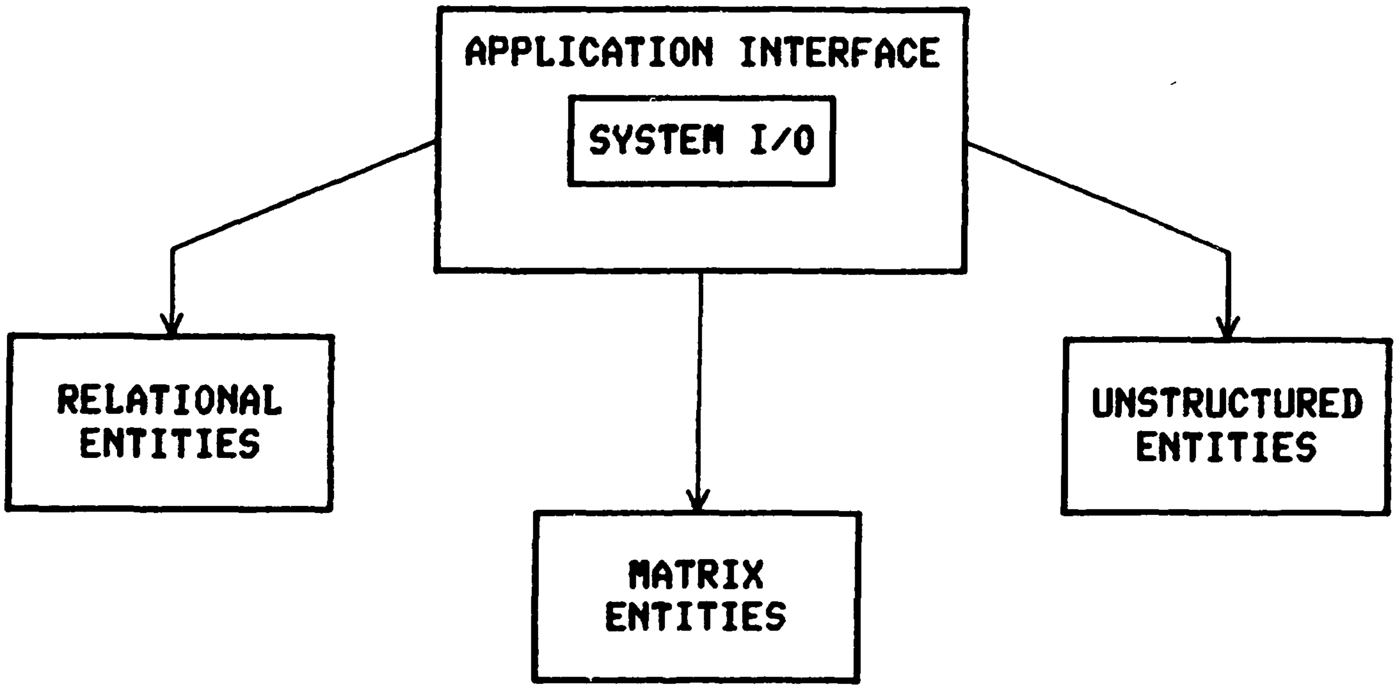
ASTROS SOFTWARE DESIGN

THE CADDB DATA STRUCTURES



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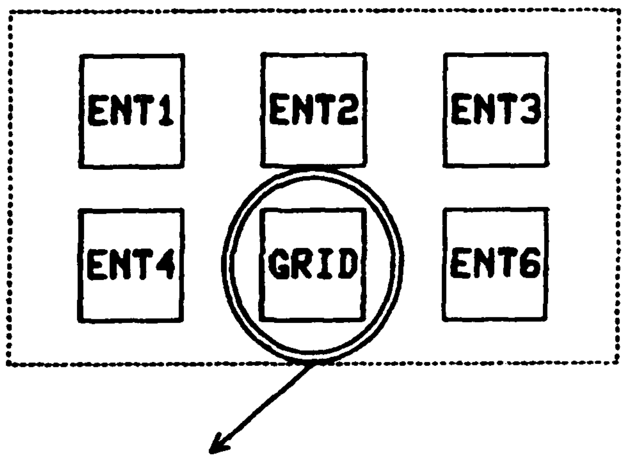
ASTROS SOFTWARE DESIGN

CADDB - RELATIONAL ENTITIES

DATA BASE →



ATTRIBUTES →

GID	X	Y	Z
101	0.0	0.0	0.0
102	1.0	0.0	0.0
103	1.0	1.0	0.0
104	0.0	1.0	0.0

← ENTRIES

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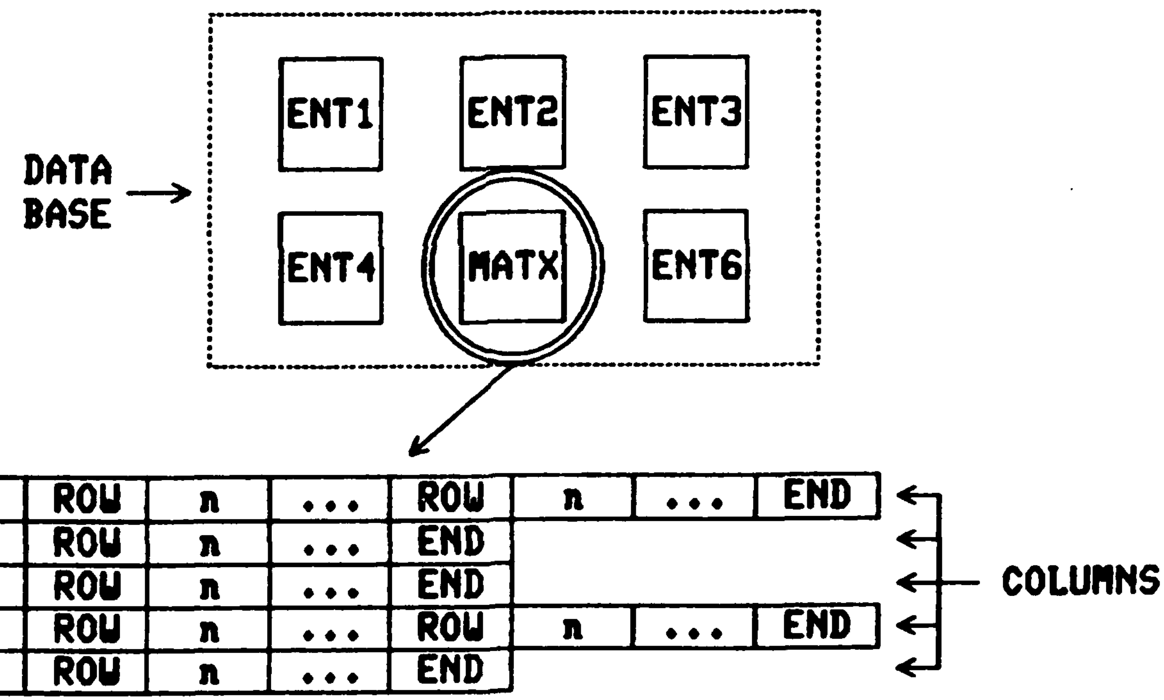
CADDB - MATRIX ENTITIES



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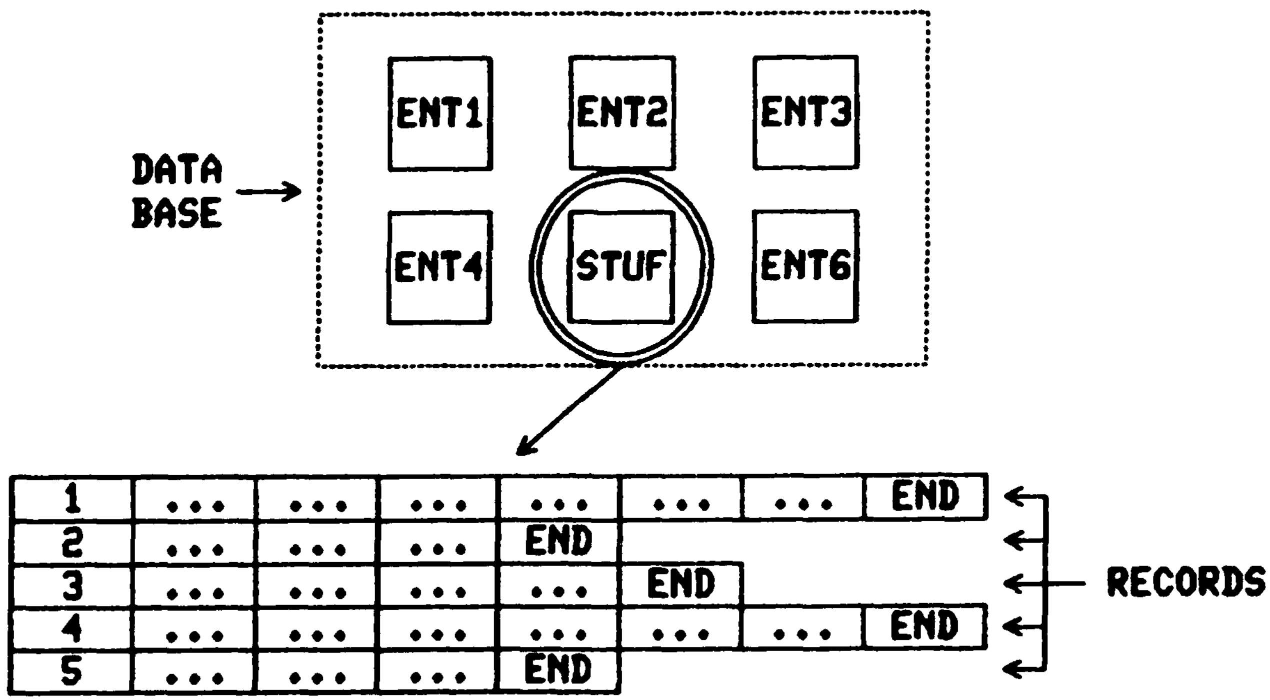
ASTROS SOFTWARE DESIGN

CADDB - UNSTRUCTURED ENTITIES



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ASTROS SOFTWARE DESIGN

WHY DYNAMIC MEMORY MANAGEMENT?

- OPEN-ENDED PROBLEM SOLVING CAPABILITY
- REUSABILITY OF MEMORY
- FLEXIBLE DATA BASE OPERATION
- BETTER SOFTWARE ENGINEERING

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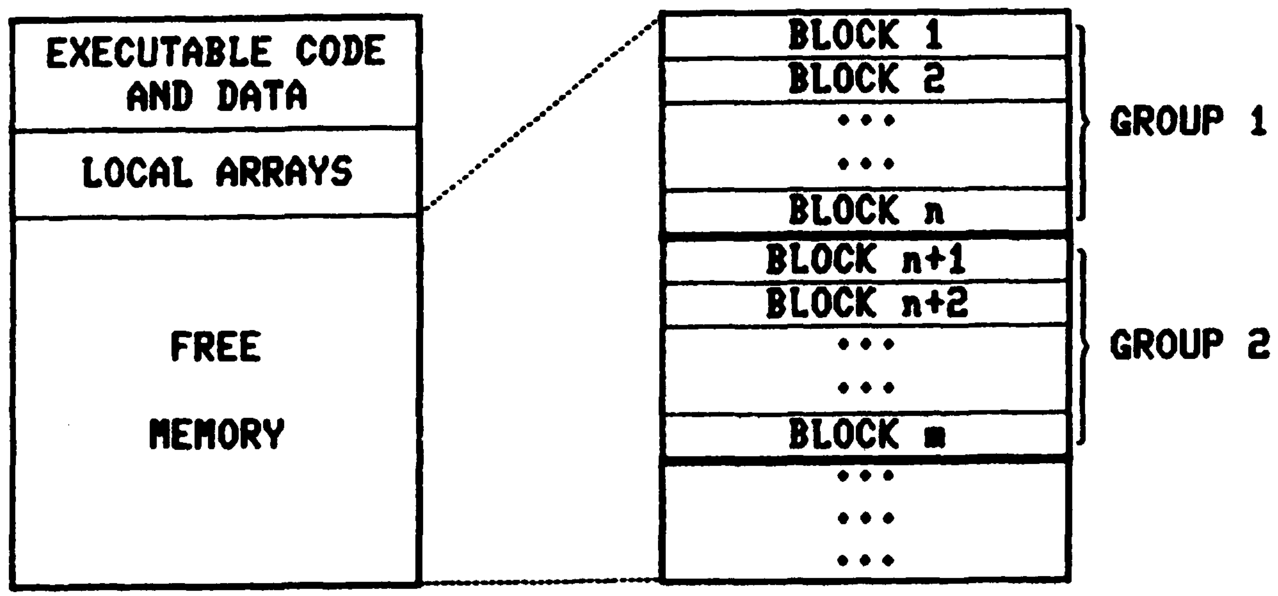
ASTROS SOFTWARE DESIGN

DYNAMIC MEMORY MANAGEMENT



ALLOCATED REGION SIZE

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ASTROS SOFTWARE DESIGN

THE DYNAMIC MEMORY MANAGER - SUBROUTINES

SUBROUTINE	FUNCTION
MMINIT	INITIALIZES THE DYNAMIC MEMORY MANAGER. USED ONLY BY THE EXECUTIVE SYSTEM.
MMBASE MMBASC	USED BY EACH MODULE TO DEFINE THE LOCATION OF THE MEMORY BASE ADDRESS.
MMGETB	GETS A BLOCK OF MEMORY OF THE SPECIFIED TYPE AND LENGTH.
MMSTAT	RETURNS THE MAXIMUM CONTIGUOUS MEMORY THAT IS AVAILABLE TO THE MODULE.
MMFREE MMFREG	FREES ALLOCATED MEMORY BY INDIVIDUAL BLOCKS OR BY GROUPS OF BLOCKS.
MMSQUZ	COMPRESSES MEMORY I/O AREAS

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ASTROS SOFTWARE DESIGN

CADDB - GENERAL DATA BASE UTILITIES

SUBROUTINE	FUNCTION
DBCREA	CREATES A DATA BASE ENTITY.
DBOPEN	OPENS A DATA BASE ENTITY PRIOR TO I/O.
DBRENA	RENAMES A DATA BASE ENTITY.
DBSWCH	INTERCHANGES THE NAMES OF TWO ENTITIES.
DBDEST	DESTROYS, OR REMOVES, AN ENTITY AND ALL OF ITS DATA FROM THE DATA BASE.
DBFLSH	REMOVES THE DATA CONTENTS OF AN ENTITY.
DBCLOS	TERMINATES I/O FOR AN ENTITY.

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ASTROS SOFTWARE DESIGN

CADDB - RELATIONAL UTILITIES

SUBROUTINE	FUNCTION
RESCHM	DEFINES THE SCHEMA OF A RELATION.
REPROJ	DEFINES THE PROJECTION OF THE RELATION PRIOR TO I/O ACTIVITY.
REQURY	QUERIES THE SCHEMA OF A RELATION.
REGET REGETM	GETS, OR FETCHES, A QUALIFIED ENTRY FROM A RELATION.
REUPD REUPDM	UPDATES THE CURRENT ENTRY OF A RELATION.
READD READDM	ADDS A NEW ENTRY TO A RELATION.

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ASTROS SOFTWARE DESIGN

CADDB - RELATIONAL UTILITIES (CONT'D)

SUBROUTINE	FUNCTION
REPOS	POSITIONS THE RELATION TO AN ENTRY.
RECOND RESETC	DEFINES CONSTRAINTS OR "WHERE" CONDITIONS FOR THE RELATION.
REGB REGBM	GETS, OR FETCHES, ALL OF THE QUALIFIED ENTRIES FROM A RELATION.
REAB REABM	ADDS A GROUP OF ENTRIES TO A RELATION.
RESORT	SORTS THE ENTRIES OF A RELATION.

ASTROS SOFTWARE DESIGN

CADDB - MATRIX UTILITIES

SUBROUTINE	FUNCTION
MXINIT	INITIALIZES A MATRIX ENTITY FOR I/O.
MXPOS MXRPOS MXNPOS	POSITIONS TO A SPECIFIED MATRIX COLUMN.
MXSTAT	GETS MATRIX COLUMN INFORMATION.
MXPAK	PACKS A COLUMN OF A MATRIX.
MXUNP	UNPACKS A COLUMN OF A MATRIX.
MXPKTI MXPKT MXPKTM MXPKTF	PACKS A COLUMN OF A MATRIX EITHER TERM-BY-TERM OR BY PARTIAL COLUMN.
MXUPTI MXUPT MXUPTM MXUPTF	UNPACKS A COLUMN OF A MATRIX EITHER TERM-BY-TERM OR BY PARTIAL COLUMN.

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ASTROS SOFTWARE DESIGN

CADDB - UNSTRUCTURED ENTITIES

SUBROUTINE	FUNCTION
UNPOS UNRPOS	POSITIONS TO A GIVEN UNSTRUCTURED RECORD.
UNSTAT	RETURNS THE LENGTH OF A RECORD.
UNGET	GETS, OR FETCHES, AND ENTIRE RECORD.
UNGETP	GETS, OR FETCHES, A PARTIAL RECORD.
UNPUT	ADDS A NEW RECORD TO THE UNSTRUCTURED ENTITY.
UNPUTP	ADDS A PARTIAL RECORD TO THE ENTITY.

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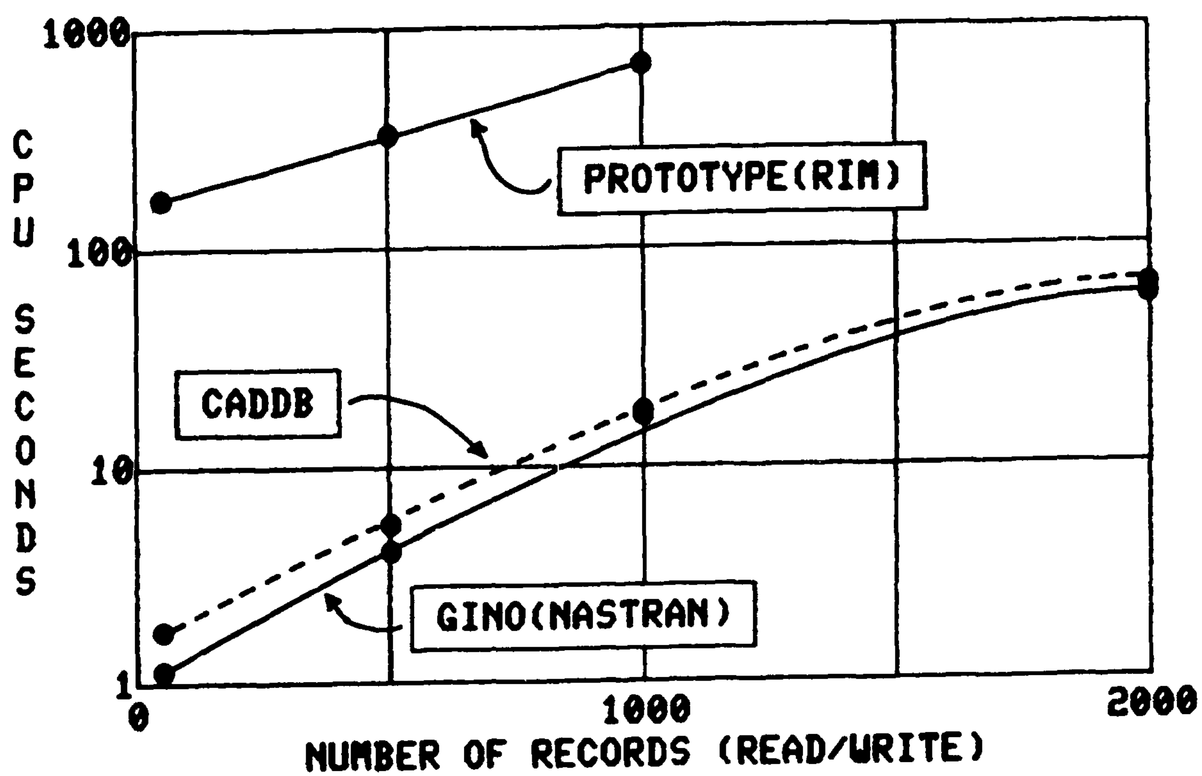
ASTROS SOFTWARE DESIGN

CADDB PERFORMANCE - UNSTRUCTURED ENTITIES



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THE ARCHITECTURE OF THE ASTROS EXECUTIVE SYSTEM

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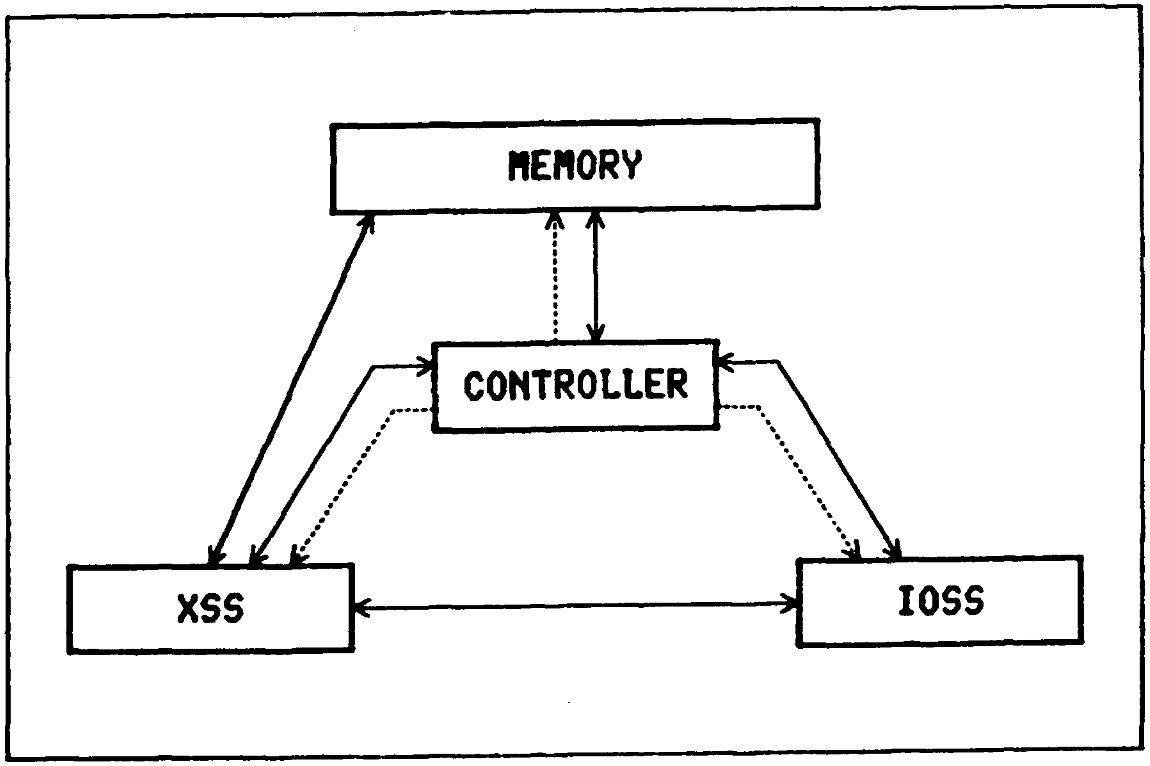
ASTROS SOFTWARE DESIGN

THE ASTROS "MACHINE"



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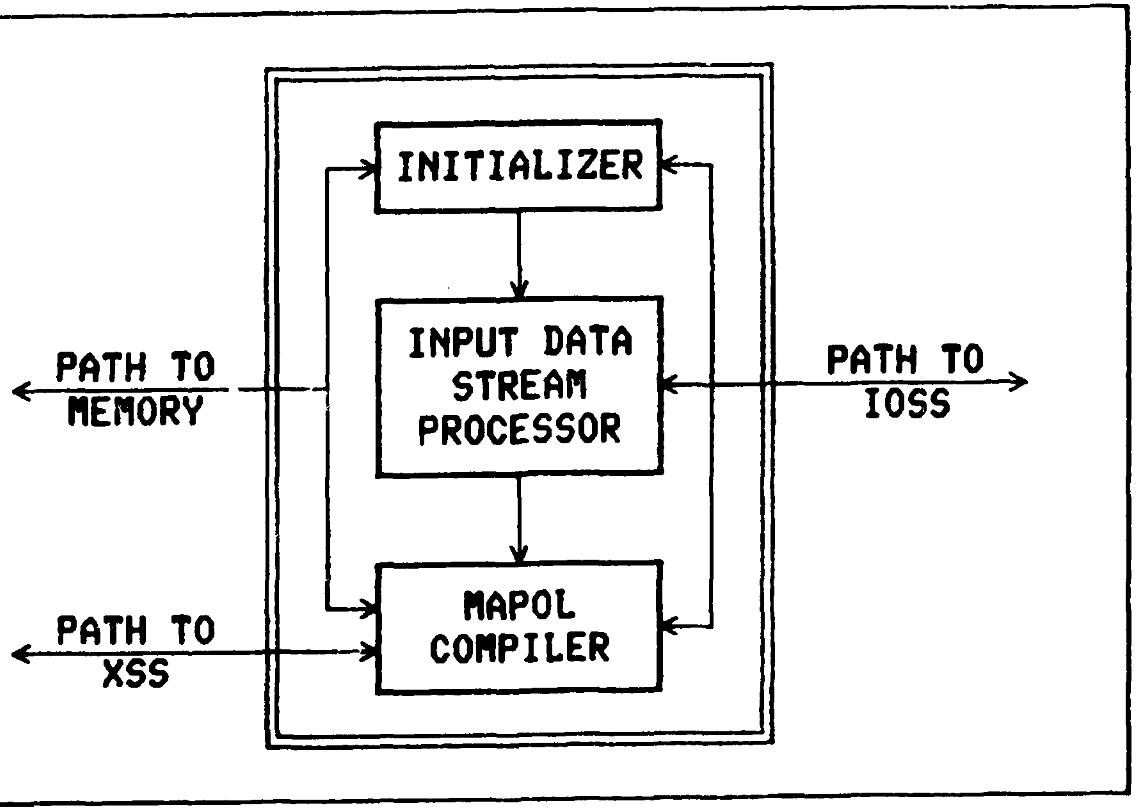
ASTROS SOFTWARE DESIGN

THE CONTROLLER



ASTROS SOFTWARE DESIGN

THE MAPOL LANGUAGE

- HIGH-ORDER, PROBLEM ORIENTED
- FLEXIBLE SYSTEM CONTROL MECHANISM
- ALGORITHM/CONCEPT DEVELOPMENT
- USER CODE INTERFACE

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ASTROS SOFTWARE DESIGN

THE MAPOL LANGUAGE - SIMPLE DATA TYPES

```
INTEGER A,B,C;
REAL D,E,F;
COMPLEX I;
LOGICAL K,L,M;
LABEL LAB1,LAB2;
```

ALL EXCEPT LABEL MAY BE ARRAYS:

```
INTEGER A(10),B(5);
COMPLEX D(11);
LOGICAL I(5,5);
```

THE IMPLEMENTATION LIMIT IS TWO SUBSCRIPTS

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ASTROS SOFTWARE DESIGN

MAPOL LANGUAGE - COMPLEX DATA TYPES

```
MATRIX [A],[B],[C];

MATRIX [X(10)],[Y(3)];

RELATION R USING I,J,K;
```

RELATIONAL ATTRIBUTES MUST BE DECLARED

MATRICES MAY HAVE A SINGLE SUBSCRIPT

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ASTROS SOFTWARE DESIGN

SAMPLE MAPOL GRAMMAR - OPERATOR PRECEDENCE RELATIONS

```
<SASSIGN>   :==  <SVAR>   :=  <SEXPR>
<SEXPR>     :==  <SEXPR>  +   <STERM>
<SEXPR>     :==  <SEXPR>  -   <STERM>
<SEXPR>     :==  +  <STERM>
<SEXPR>     :==  -  <STERM>
<SEXPR>     :==  <STERM>
<STERM>     :==  <STERM>  *   <SFACTOR>
<STERM>     :==  <STERM>  /   <SFACTOR>
<STERM>     :==  <SFACTOR>
<SFACTOR>   :==  <SPRIM>  **  <SFACTOR>
<SFACTOR>   :==  <SPRIM>
<SPRIM>     :==  <SVAR>
<SPRIM>     :==  CONST
<SPRIM>     :==  (  <SEXPR>  )
```

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ASTROS SOFTWARE DESIGN

MAPOL LANGUAGE - LOOPING CONSTRUCTS

```
WHILE X<3 DO
...
...
...
ENDDO;
```

```
FOR I=1 TO 17 DO
...
...
...
ENDDO;
```

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MAPOL LANGUAGE - OPERATIONS

ARITHMETIC	LOGICAL	RELATIONAL	MATRIX
**	.AND.	=	*
*	.OR.	>	+
/	.XOR.	<	-
+	.NOT.	>=	()[]
-		<=	
		<>	

OPERATORS ARE POLYMORPHIC

ARITHMETIC DONE IN "HIGHEST" TYPE

ASSIGNMENT DETERMINES FINAL TYPE

ASTROS SOFTWARE DESIGN

MAPOL LANGUAGE - INLINE PROCEDURES

```
PROC USQRT(A,SQRTA);
REAL A,SQRTA,EPS,DELTA,AOLD;
     EPS := 0.001;
     SQRTA := 1.0;
     DELTA := 1.0;
     WHILE ABS(DELTA)>EPS DO
         AOLD := SQRTA;
         SQRTA := AOLD - ((AOLD*AOLD-A)/(2.0*AOLD));
         DELTA := SQRTA - AOLD;
     ENDDO;
ENDP;
```

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MAPOL LANGUAGE - MATRIX OPERATIONS

SAMPLE PROBLEM

FOR USER-INPUT MATRICES A,B AND C AND REAL PARAMETERS ALPHA AND BETA, WE WISH TO COMPUTE THE MATRIX X DEFINED BY:

$[X] = [A][B] + [C]$ IF ALPHA < 0

$[X] = [\ BETA[A] + [B]\ ]^T$ IF ALPHA = 0

$[X] = [A][C]^{-1}[B]$ IF ALPHA > 0

ASTROS SOFTWARE DESIGN

MAPOL LANGUAGE - MATRIX OPERATIONS

```
MATRIX [X],[A],[B],[C];
REAL ALPHA,BETA;
    IF ALPHA<0 THEN
        [X] := [A] * [B] + [C];
    ELSE
        IF ALPHA=0 THEN
            [X] := TRANS( BETA[A] + [B] );
        ELSE
            [X] := [A] * INV([C]) * [B];
        ENDIF;
    ENDIF;
END;
```

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ASTROS SOFTWARE DESIGN

THE MAPOL COMPILER - PEEPHOLE OPTIMIZATION

THE MAPOL CODE: A:=B*C+D;

YIELDS THE EXECUTABLE:

```
PUSHM A
PUSHM B
PUSHM C
MAT*
PUSHM D
MAT+
SWITCH
```

BUT, IF A,B,C, AND D ARE MATRICES...

```
PUSHM A
PUSHM B
PUSHM C
PUSHM D
PUSHI 4
CALL 'MPYAD'
SWITCH
```

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ASTROS SOFTWARE DESIGN

DATA BASE OPERATIONS

DATA BASE	DBOPEN DBCLOS
RELATIONS	DBMAKE DBUSE DBEND
ENTRIES	DBGET DBPUT DBADD DBDEL
QUALIFICATION	DBCOND

THESE MAPOL UTILITIES ARE NOT 1-1 WITH APPLICATION ROUTINES

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MAPOL LANGUAGE - DATABASE OPERATIONS

SAMPLE PROBLEM

THERE IS A RELATION CALLED 'GRID' THAT EXISTS ON THE ASTROS DATA BASE. THE ATTRIBUTES OF 'GRID' ARE:

GID - ID OF THE GRID POINT (INTEGER)
X - THE X COORDINATE OF THE GRID (REAL)
Y - THE Y COORDINATE OF THE GRID (REAL)
Z - THE Z COORDINATE OF THE GRID (REAL)

WE WISH TO COMPUTE THE DISTANCE FROM THE FIRST GRID POINT TO EACH OF THE OTHERS.

ASTROS SOFTWARE DESIGN

MAPOL LANGUAGE - DATABASE OPERATIONS

```
REAL DEL(100),X1,X2,X3;
INTEGER I,L;
RELATION GRID USING GID,X,Y,Z;
     CALL DBUSE( GRID , L );
     CALL DBGET( GRID );
     X1 := GRID.X;
     X2 := GRID.Y;
     X3 := GRID.Z;
     FOR I = 2 TO L DO
          CALL DBGET( GRID );
          DEL(I) := SQRT( (X1-GRID.X)**2 + (X2-GRID.Y)**2 +
                    (X3-GRID.Z)**2 );
     ENDDO;
     CALL DBEND( GRID );
END;
```

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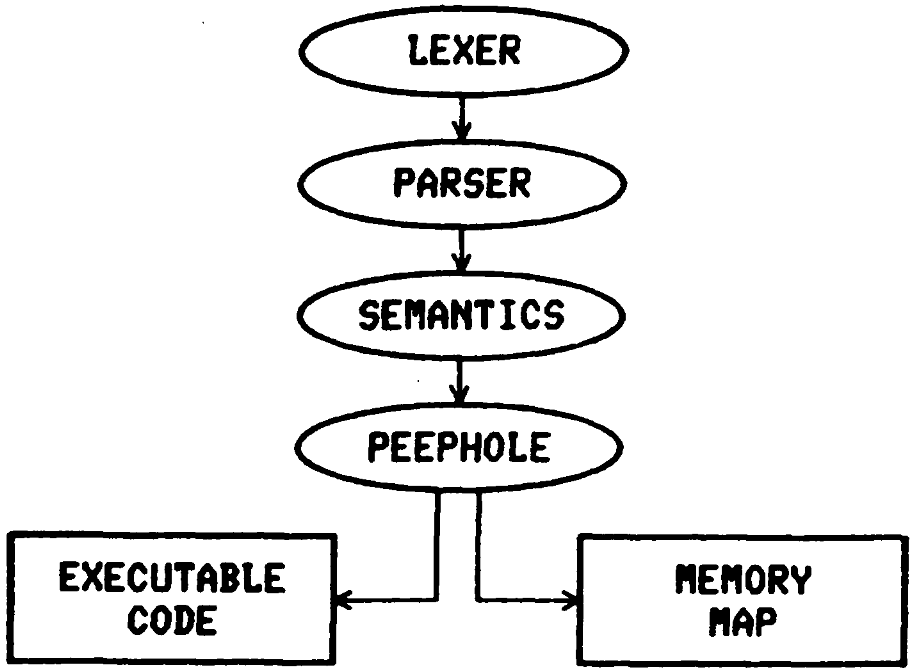
ASTROS SOFTWARE DESIGN

THE MAPOL COMPILER



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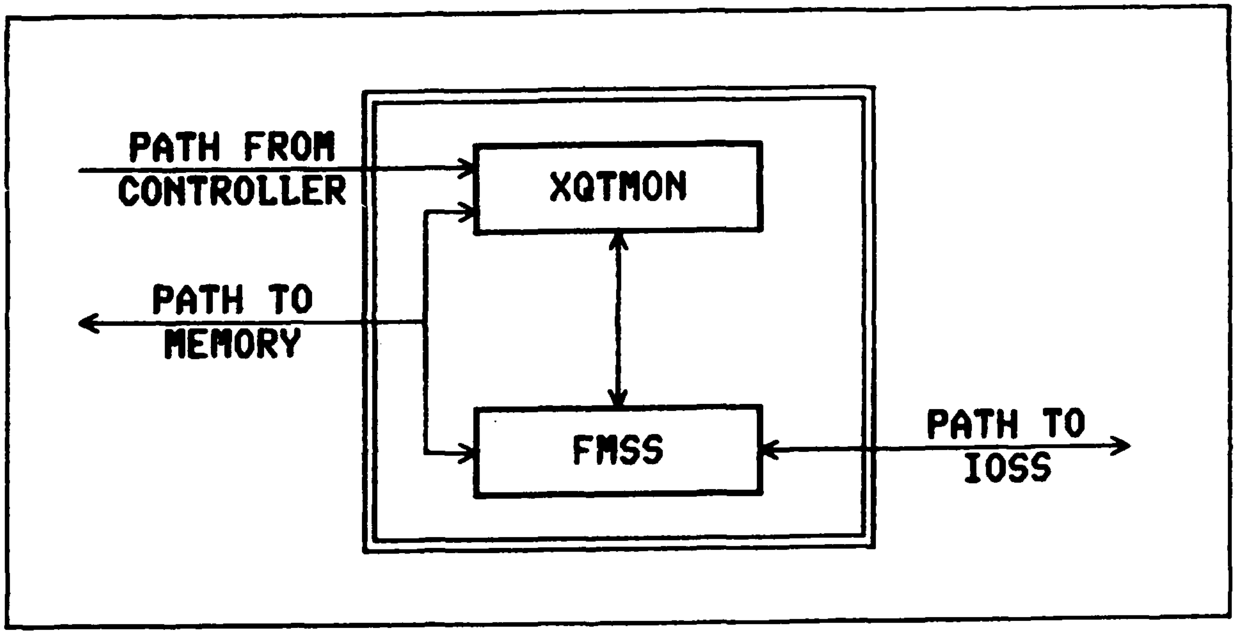
ASTROS SOFTWARE DESIGN

THE EXECUTION SUBSYSTEM (XSS)



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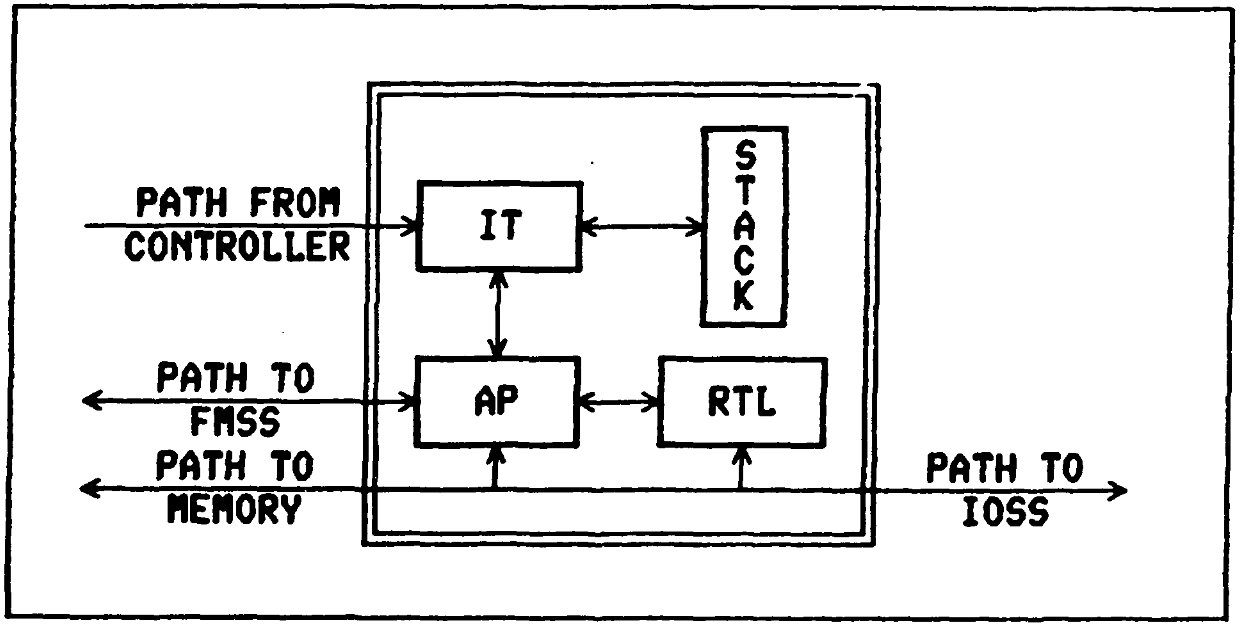
ASTROS SOFTWARE DESIGN

THE EXECUTION MONITOR (XQTMON)



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ASTROS SOFTWARE DESIGN

THE RUN-TIME ENVIRONMENT

- STACK MODEL OF EXECUTION
- ONE-ADDRESS CODE
- HIGH-ORDER "MEMORY"

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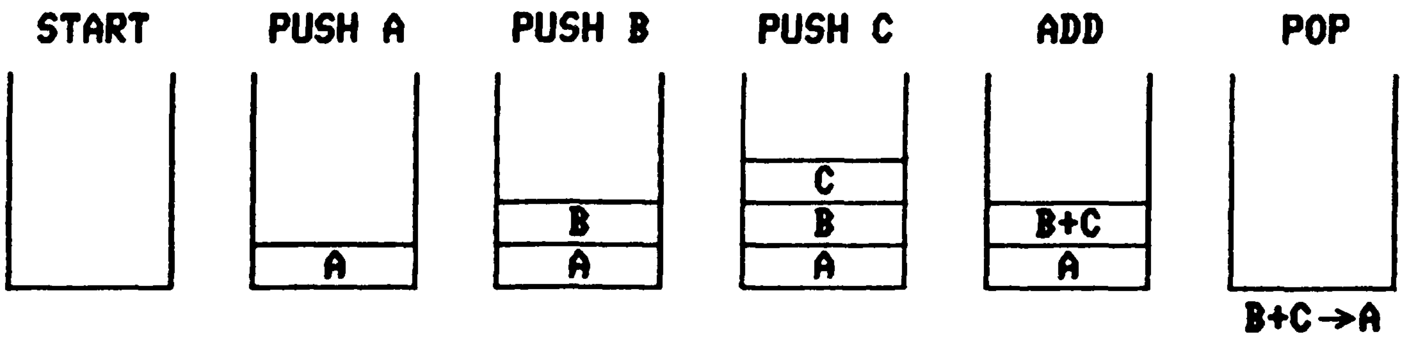
THE STACK MODEL OF EXECUTION

SOURCE STATEMENT: A := B + C;

EXECUTABLE CODE:

```
PUSH A
PUSH B
PUSH C
ADD
POP
```

THE INSTRUCTION STACK



ASTROS SOFTWARE DESIGN

THE INSTRUCTION TRANSLATOR

- FETCHS EXECUTABLE INSTRUCTIONS
- TRANSLATES INSTRUCTIONS
- LOADS OPERANDS INTO STACK
- BRANCHES TO AP, RTL, OR FMSS

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ASTROS SOFTWARE DESIGN

THE ASTROS "MACHINE" INSTRUCTION SET

STACK
PUSH
PUSHI
PUSHR
POP

LINKAGE
GOSUBX
GOSUBU
GOMOD

BRANCHING
JMP
JLT
JGT
JLE
JGE
JNE

OTHER
REF
NOP
HALT
ATTR

OPERATORS
NEG
ADD
SUB
MUL
DIV
EXP

PROCS
LPARM
RETURN

LOOPING
INCRE
LOOPE

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ASTROS SOFTWARE DESIGN

THE ARITHMETIC PROCESSOR (AP)

- STANDARD MATHEMATICAL OPERATIONS

  ADDITION
  SUBTRACTION
  MULTIPLICATION
  DIVISION
  EXPONENTIATION

- LOGICAL OPERATIONS

  CONJUNCTION
  DISJUNCTION
  NEGATION
  EQUIVALENCE

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ASTROS SOFTWARE DESIGN

THE RUN-TIME LIBRARY (RTL)

- MATHEMATICAL FUNCTIONS
- MATRIX OPERATIONS
- DATA BASE OPERATIONS

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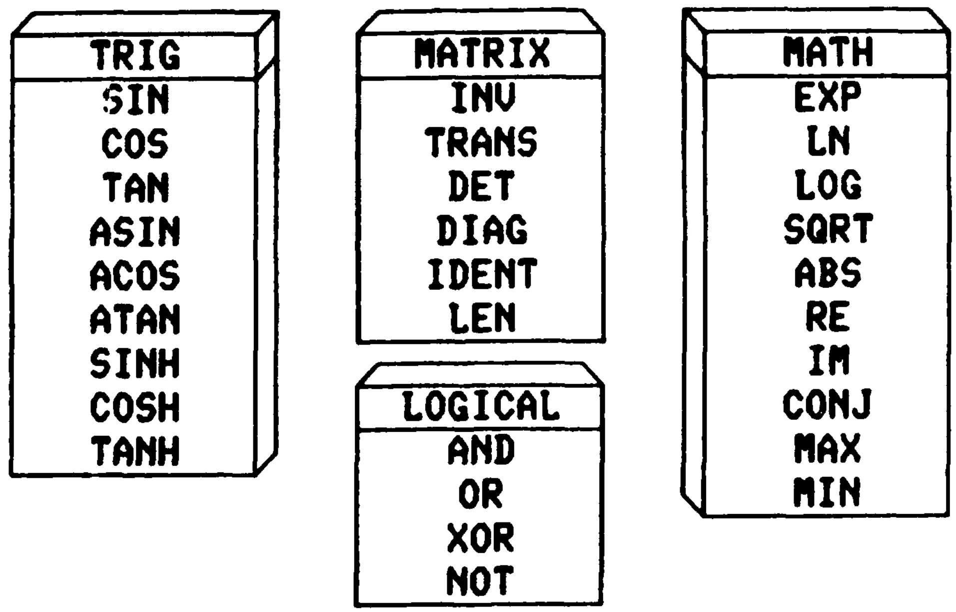
ASTROS SOFTWARE DESIGN

THE RUN-TIME LIBRARY



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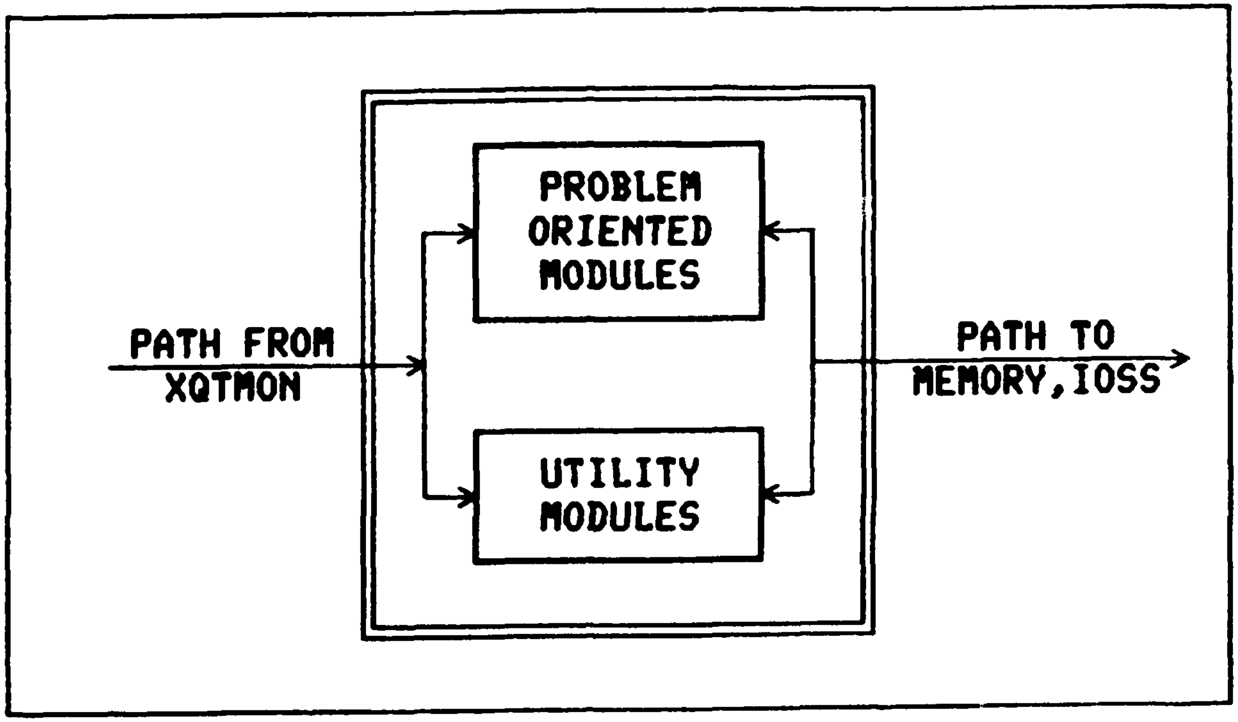
ASTROS SOFTWARE DESIGN

THE FUNCTIONAL MODULE SUBSYSTEM (FMSS)



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ASTROS SOFTWARE DESIGN

MATRIX UTILITY MODULES

PROCEDURE	BASIC OPERATION
ADD	$[A] = a[A] + b[B]$
DECOMP	$[A] \rightarrow [L][U]$
FBS	$[X] = ([L][U])^{-1}[B]$
MERGE	$[A] \rightarrow \left[\begin{array}{c:c} A11 & A12 \\ \hdashline A21 & A22 \end{array}\right]$
MPYAD	$[X] = [A][B] + [C]$
PARTN	$[A] \rightarrow \left[\begin{array}{c:c} A11 & A12 \\ \hdashline A21 & A22 \end{array}\right]$
SOLVE	$[X] = [A]^{-1}[B]$
TRANS	$[X] = [A]^T$

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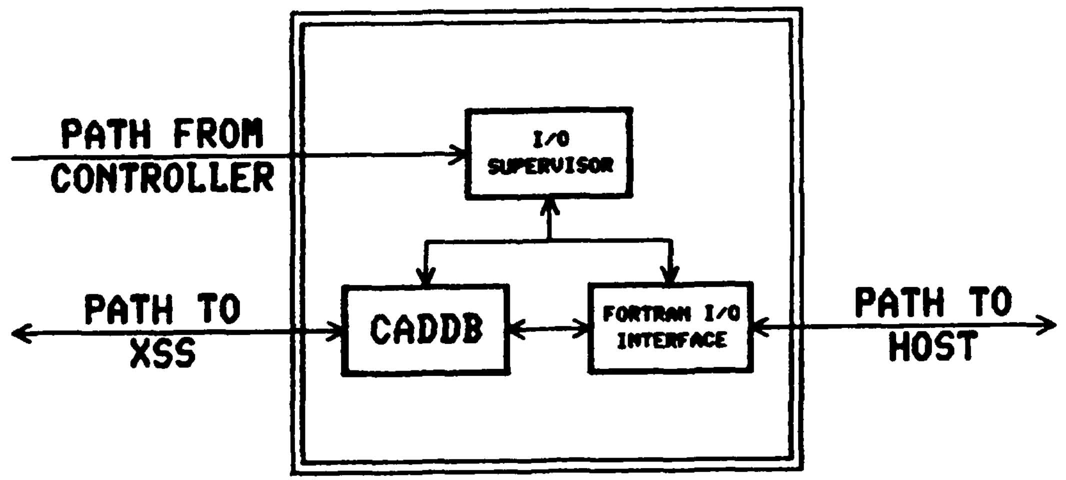
ASTROS SOFTWARE DESIGN

THE INPUT/OUTPUT SUBSYSTEM (IOSS)



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ASTROS SOFTWARE DESIGN

MEETING THE DESIGN GOALS - CONCLUSION

- CORRECTNESS AND RELIABILITY
- COST-EFFECTIVE MAINTENANCE/ENHANCEMENT
- EFFICIENT COMPUTER RESOURCE UTILIZATION
- SIMPLIFIED USER INTERFACE
- PORTABILITY TO NEW COMPUTERS
- PROTOTYPES HAVE PROVEN CONCEPT

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ASTROS User Training Workshop

20-24 June 1988

ICE - The Interactive CADDB Environment

David L. Herendeen

Universal Analytics, Inc.

ICE: What and Why

- ICE is an Interactive Interface for ASTROS
- ICE is an SQL-Compatible Database Management System
- ICE has been Extended for Scientific Data Requirements
- ICE can Assist in Reviewing ASTROS Results because:
  - They May Be Voluminous
  - They are Often Complex
  - They May Be Needed for Other Analyses

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Classification of ICE Commands

- CQL Command Editing
- Data Retrieval - Relations
- Creating Views of Entities
- Selective Modification of Data
- Environment Commands
- Security Commands
- Entity Creation
- Data Retrieval - Matrices
- Inserting Data into Entities
- Removing Entities and Data
- Report Generation Commands
- Utility Commands

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CQL Command Editing

- **LIST** [line_1 [**TO** line_n]];
- **DELETE** [line_1 [**TO** line_n]];
- **ENTER** "new_line";
- **CHANGE** "string_1" "string_2";
- **RUN;**

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Creating Database Entities

- **DESCRIBE** [entity_name];
- **CREATE RELATION** relation_name
  { (<schema_list>) |
  LIKE old_rel_name };
- **CREATE MATRIX** matrix_name
  { (<matrix_attributes>) |
  LIKE old_mat_name };

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The DESCRIBE Command

```
ICE> DESCRIBE;
.... ENTITY NAME  TYPE  SIZE
.... -----------  ----  ----
.... GRID         REL     10
.... QUAD4        REL      4
.... PSHELL       REL      3
.... Q4STR001     REL      4
.... Q4STR002     REL      4
.... KGG          MAT      5
.... UNKNOWN      UN       1
```

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The DESCRIBE Command

```
ICE> DESCRIBE PSHELL;
.... RELATION  PSHELL SCHEMA IS:
.... ATTRIBUTE  TYPE    LEN
.... ---------  ----  -----
.... PID        INT       1
.... MID        INT       1
.... T          RSP       1
.... CURRENT CONTENTS  3 ENTRIES
```

```
ICE> DESCRIBE KGG;
.... REAL, DOUBLE PRECISION, SYMMETRIC MATRIX KGG
....   5 ROWS,    5 COLUMNS,   DENSITY = 52.0%
```

```
ICE> DESCRIBE UNKNOWN;
.... UNSTRUCTURED ENTITY UNKNOWN
....    8 RECORDS, LONGEST RECORD IS 2044
```

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The CREATE RELATION Command

```
ICE> CREATE RELATION GRIDX
  2>   ( GID INT KEY,
  3>     CID INT,
  4>     X   RSP,
  5>     Y   RSP,
  6>     Z   RSP );
```

attribute_type	*DESCRIPTION*	*attribute_length*	CAN BE KEY?
INT	Integer value	Not Used	YES
AINT	Array of Integer Values	Number of Elements in Array	NO
RSP	Real Single Precision Values	Not Used	NO
ARSP	Array of Real Single Precision Values	Number of Element in Array	NO
RDP	Real Double Precision Values	Not Used	NO
ARDP	Array of Real Double Precision Values	Number of Elelement in Array	NO
STR	Character String	Number of Characters in String	YES

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The CREATE MATRIX Command

```
ICE> CREATE MATRIX NEWKGG
  2>   ( TYPE RDP,
  3>     FORM SYMMETRIC,
  4>     ROWS 5 );
```

ATTRIBUTE	KEYWORD	DESCRIPTION
data type	**RSP**	Real Single Precision Terms
	RDP	Real Double Precision Terms
	CSP	Complex Single Precision Values
	CDP	Complex Double Precision Values
shape	**RECTANGULAR**	Rectangular; n x m
	SYMMETRIC	Symmetric, $A_{ij} = A_{ji}$
	DIAGONAL	Diagonal, $A_{ij} \equiv 0 \ \forall i \neq j$
	IDENTITY	Identity; $A_{ii} \equiv 1.0, A_{ij} \equiv 0 \ \forall i \neq j$

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Retrieving Data from Relations

- **SELECT** <select_list> <FROM_part>
  [<WHERE_part>][<GROUP_part>]
  [<SORT_part>];
- <WHERE_part> → **WHERE** <search_condition>
- <GROUP_part> → **GROUP BY** <attribute_list>
- <SORT_part> → **SORT BY** <sort_list>

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SELECTing Data from Relations

```
ICE> SELECT EID,PID,G1,G2,G3,G4 FROM QUAD4;

  EID    PID     G1     G2     G3     G4
-----  -----  -----  -----  -----  -----
    1      1      1      2      7      6
    2      2      2      3      8      7
    3      1      3      4      9      8
    4      2      4      5     10      9
```

```
ICE> SELECT G4,G1 FROM QUAD4;

   G4     G1
-----  -----
    6      1
    7      2
    8      3
    9      4
```

UNIVERSAL ANALYTICS, INC.

SELECTing Data from Relations

```
ICE> SELECT DISTINCT PID FROM QUAD4;

  PID
-----
    1
    2
```

```
ICE> SELECT EID,PID,GRIDS FROM QUAD4;

  EID    PID                     GRIDS(4)
-----  -----  --------------------------
    1      1      1      2      7      6
    2      2      2      3      8      7
    3      1      3      4      9      8
    4      2      4      5     10      9
```

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Qualifying the SELECTion

```
ICE> SELECT * FROM GRID WHERE X > 3.0;

  GID    CID            X            Y            Z
-----  -----  -----------  -----------  -----------
    5      0  4.00000E+00  1.00000E+00  0.00000E+00
   10      0  4.00000E+00  0.00000E+00  0.00000E+00
```

```
ICE> SELECT GID FROM GRID WHERE X > 2.0 AND Y = 0.0;

  GID
-----
    9
   10
```

UNIVERSAL ANALYTICS, INC.

Qualifying the SELECTion

```
ICE> SELECT GID,X FROM GRID
  2>     WHERE ( X > 2.0 AND Y = 0.0 )
  3>     OR      GID = 1;

  GID            X
-----  ------------
    1   0.00000E+00
    9   3.00000E+00
   10   4.00000E+00
```

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SELECTing from a Set

```
ICE> SELECT GID,X,Y,Z FROM GRID WHERE X IN (3.0,4.0);

  GID             X             Y             Z
-----  ------------  ------------  ------------
    4   3.00000E+00   1.00000E+00   0.00000E+00
    5   4.00000E+00   1.00000E+00   0.00000E+00
    9   3.00000E+00   0.00000E+00   0.00000E+00
   10   4.00000E+00   0.00000E+00   0.00000E+00
```

Using Arithmetic Expressions

```
ICE> SELECT GID,SQRT(X**2+Y**2+Z**2) FROM GRID
  2>      WHERE Y = 1.0;

  GID  SQRT(X**2+Y**2+Z**2)
-----  --------------------
    1           1.00000E+00
    2           1.41421E+00
    3           2.23607E+00
    4           3.16228E+00
    5           4.12311E+00
```

```
ICE> SELECT EID,SIGY FROM Q4STR001 WHERE
  2>      SIGY >= 2.0*SIGX;

  EID          SIGY
-----  ------------
    1   2.00000E+06
    2   1.00000E+07
```

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Using Arithmetic Expressions

FUNCTION	PURPOSE	ATTRIBUTE RESTRICTIONS
ABS(x)	Absolute value	RSP, RDP or INT x
ACOS(x)	Inverse trigonometric cosine	RSP or RDP x
ASIN(x)	Inverse trigonometric sine	RSP or RDP x
ATAN(x)	Inverse trigonometric tangent	RSP or RDP x
COS(X)	Trigonometric sine	RSP, RDP or int x
COSH(x)	Hyperbolic cosine	RSP, RDP or INT x
DBLE(x)	Convert to RDP	RSP or INT x
EXP(x)	Exponential function e^x	RSP or RDP x
FLOAT(i)	Convert to RSP	INT i
INT(x)	Convert to INT	RSP or RDP x
LN(x)	Natural (base e) logarithm	RSP, RDP or INT x
LOG(x)	Common (base 10) logarithm	RSP, RDP or INT x
SIN(x)	Trigonomtric sine	RSP, RDP or INT x
SINH(x)	Hyperbolic sine	RSP, RDP or INT x
SQRT(x)	Square root	RSP, RDP, or INT x
TAN(x)	Trigonometric tangent	RSP, RDP, or INT x
TANH(x)	Hyperbolic tangent	RSP, RDP or INT x

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Grouping the Results

```
ICE> SELECT PID FROM QUAD4
  2>     GROUP BY PID;

  PID
-----
    1
    2
```

```
ICE> SELECT QUAD4.PID,MAX(Q4STR001.SIGX)
  2>     FROM QUAD4,Q4STR001
  3>     WHERE QUAD4.EID = Q4STR001.EID
  4>     GROUP BY QUAD4.PID;

  PID     MAX(SIGX)
-----  ------------
    1   2.00000E+06
    2   3.00000E+06
```

Sorting the Results

```
ICE> SELECT * FROM Q4STR001
  2>     SORT BY SIGX,SIGY;

  EID          SIGX          SIGY         TAUXY
-----  ------------  ------------  ------------
    1   1.00000E+06   2.00000E+06   4.00000E+04
    4   2.00000E+06   1.00000E+06   5.00000E+04
    3   2.00000E+06   3.00000E+06   4.00000E+04
    2   3.00000E+06   1.00000E+07   6.00000E+03
```

```
ICE> SELECT QUAD4.PID,MAX(Q4STR001.SIGX)
  2>     FROM QUAD4,Q4STR001
  3>     WHERE QUAD4.EID=Q4STR001.EID
  4>     GROUP BY QUAD4.PID
  5>     SORT BY 2 DESC;

  PID     MAX(SIGX)
-----  ------------
    2   3.00000E+06
    1   2.00000E+06
```

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The SUBQUERY

```
ICE> SELECT PID FROM QUAD4 WHERE EID=4;

  PID
-----
    2

ICE> SELECT T FROM PSHELL WHERE PID=2;

           T
------------
 5.00000E-01
```

```
ICE> SELECT T FROM PSHELL WHERE
  2>      PID = ( SELECT PID FROM QUAD4 WHERE
  3>                 EID=4 );

           T
------------
 5.00000E-01
```

The SUBQUERY

```
ICE> SELECT EID,TAUXY FROM Q4STR001 WHERE
  2>      TAUXY > ALL ( SELECT TAUXY FROM Q4STR002 );

  EID          TAUXY
-----   ------------
    1   4.00000E+04
    3   4.00000E+04
    4   5.00000E+04
```

```
ICE> SELECT EID FROM QUAD4
  2>  WHERE PID IN ( SELECT PID FROM PSHELL
  3>                 WHERE T = 0.5 )
  4>  AND EID IN ( SELECT EID FROM Q4STR001
  5>                 WHERE SIGX > 2.0E+6 );

  EID
-----
    2
```

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The SUBQUERY

```
ICE> SELECT GID,X FROM GRID
  2>   WHERE GID IN ( SELECT G1 FROM QUAD4 WHERE
  3>                   PID IN ( SELECT PID FROM PSHELL WHERE
  4>                               T = 0.01 ));

  GID              X
-----   ------------
    1    0.00000E+00
    3    2.00000E+00
```

UNIVERSAL ANALYTICS, INC.

The Group Operators

```
ICE>  SELECT AVG(X) FROM GRID WHERE Y = 1.0;

       AVG(X)
------------
 2.00000E+00
```

GROUP OPERATOR	DESCRIPTION
AVG	Computes the average value of the specified attribute expression for all entries which satisfy the selection criteria.
SUM	Computes the algebraic sum of the attribute expression values.
MIN	Finds the minimum of the qualified attribute selection.
MAX	Finds the maximum of the qualified attrribute selection.
COUNT	Counts the number of entries which satisfy the given selection criteria.

The Group OperatorsI

```
CE> SELECT MAX(SIGX),MIN(SIGY)
  2>      FROM Q4STR001;

   MAX(SIGX)      MIN(SIGY)
------------  ------------
 3.00000E+06   1.00000E+06
```

```
ICE> SELECT GID FROM GRID
  2>      WHERE X = ( SELECT MAX(X) FROM GRID );

  GID
-----
    5
   10
```

UNIVERSAL ANALYTICS, INC.

The Group Operators

```
ICE> SELECT PID,MAX(G3) FROM QUAD4
  2>      GROUP BY PID;

  PID  MAX(G3)
-----  -------
    1        9
    2       10
```

```
ICE> SELECT COUNT(*) FROM QUAD4
  2      WHERE PID = 2;
COUNT(*)
--------
       2
```

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The JOIN Operation

```
ICE> SELECT EID,QUAD4.PID,MID FROM
  2>      QUAD4,PSHELL
  3>         WHERE EID = 1
  4>         AND   QUAD4.PID = PSHELL.PID

  EID    PID    MID
-----  -----  -----
    1      1    101
```

```
ICE> SELECT EID,QUAD4.PID,MID FROM
  2>      QUAD4,PSHELL WHERE
  3>         QUAD4.PID = PSHELL.PID;

  EID    PID    MID
-----  -----  -----
    1      1    101
    2      2    201
    3      1    101
    4      2    201
```

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Relational Algebra

- **SELECT INTERSECTION OF** rel_name_1
  AND rel_name_2
  [AS rel_name_3 **];**

- **SELECT UNION OF** rel_name_1
  AND rel_name_2
  [AS rel_name_3 **];**

- **SELECT DIFFERENCE OF** rel_name_1
  AND rel_name_2
  [AS rel_name_3 **];**

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Retrieving Data from Matrices

- **SELECT COLUMNS**
  [({ FULL | STRING | BAND })]
  column_list
  FROM matrix_name
  [<WHERE_part>];

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The SELECT COLUMNS Command

```
ICE> SELECT COLUMNS(FULL) * FROM KGG;

MATRIX KGG, REAL DOUBLE PRECISION, 5 ROWS, 5 COLUMNS
-----------------------------------------------------------
COLUMN 1
1.00000   2.00000   0.00000   0.00000   0.00000
-----------------------------------------------------------
COLUMN 2
2.00000   3.00000   4.00000   0.00000   0.00000
-----------------------------------------------------------
COLUMN 3
0.00000   4.00000   5.00000   6.00000   0.00000
-----------------------------------------------------------
COLUMN 4
0.00000   0.00000   6.00000   7.00000   8.00000
-----------------------------------------------------------
COLUMN 5
0.00000   0.00000   0.00000   8.00000   9.00000
```

UNIVERSAL ANALYTICS, INC.

The SELECT COLUMNS Command

```
ICE> SELECT COLUMNS(STRING) 1,2 FROM KGG;

MATRIX KGG, REAL DOUBLE PRECISION, 5 ROWS, 5 COLUMNS
----------------------------------------------------------
COLUMN 1, STRING 1 - BEGINS AT ROW 1
1.00000   2.00000
----------------------------------------------------------
COLUMN 2, STRING 1 - BEGINS AT ROW 1
2.00000   3.00000   4.00000
```

```
ICE> SELECT COLUMNS * FROM KGG WHERE ROWS IN (2);

MATRIX KGG, REAL DOUBLE PRECISION, 5 ROWS, 5 COLUMNS
----------------------------------------------------------
ROW 2, COLUMN 1
2.00000   3.00000   4.00000   0.00000   0.00000
```

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Creating Views of Entities

- **CREATE VIEW** relation_name
  [<attribute_name_list>]
  AS <select_part>;

- **EXTRACT MATRIX** matrix_name
  <matrix_select_part>;

UNIVERSAL ANALYTICS, INC.

The CREATE VIEW and EXTRACT MATRIX Commands

```
ICE> CREATE VIEW SIGYQ41 AS
  2>      SELECT SIGY FROM Q4STR001;
```

```
ICE> EXTRACT MATRIX KNN AS
  2>      SELECT COLUMNS 1,3,5 FROM KGG
  3>         WHERE ROW IN (1,3,5);

ICE> ... MATRIX KNN EXTRACTED
```

Inserting Data into Entities

- **INSERT INTO** relation_name <value_part>;
- <value_part> → **VALUES** (value_list)
- **INSERT INTO MATRIX** matrix_name
  <new_value_list>;
- <new_value_term> → **VALUES AT** row_id
  (string_list)

UNIVERSAL ANALYTICS, INC.

The INSERT Commands

```
ICE> INSERT INTO GRID VALUES (11,0,5.0,0.0,0.0);
....  1 ENTRY INSERTED
```

```
ICE> CREATE RELATION GRIDY1
  2> ( GID INT KEY, CID INT,
  3>   X RSP,Y RSP,Z RSP );
....  RELATION GRIDY1 CREATED
ICE> INSERT INTO GRIDY1
  2>    ( SELECT * FROM GRID
  3>         WHERE Y=1.0);
....  5 ENTRIES INSERTED
```

```
ICE> INSERT INTO MATRIX KGG
  2>    VALUES AT 2 (25.0)
  3>    VALUES AT 5 (30.0,40.0);
....  COLUMN ADDED TO KGG
```

Selective Modification of Data

- **UPDATE** relation_name **SET** new_value_list
  [<WHERE_part>];

- **UPDATE MATRIX** matrix_name **SET** column_list
  TO <value_list>;

- <value_term> → **VALUES AT** row_id (value_list)

- **ALTER** relation_name **ADD** (<new_schema_list>);

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The UPDATE Commands

```
ICE> UPDATE QUAD4 SET PID=1 WHERE EID=2;
....  1 ENTRY UPDATED
ICE> SELECT * FROM QUAD4 WHERE EID=2;
  EID    PID     G1     G2     G3     G4
-----  -----  -----  -----  -----  -----
    2      1      2      3      8      7
```

```
ICE> UPDATE PSHELL SET MID=501,T=0.25 WHERE PID=1;
....  1 ENTRY UPDATED
ICE> SELECT * FROM PSHELL;

  PID    MID            T
-----  -----  ------------
    1    501   2.50000E-01
    2    201   5.00000E-01
    3    301   3.00000E-01
```

UNIVERSAL ANALYTICS, INC.

The UPDATE Commands

```
ICE> UPDATE GRID SET Y=2.0 WHERE X=2.0 AND Y=1.0;
```

```
ICE> UPDATE QUAD4 SET PID=3
  2>      WHERE EID IN
  3>      ( SELECT EID FROM Q4STR001
  4>           WHERE SIGY > 2.0E+6 );

....  2 ENTRIES UPDATED
ICE> SELECT EID,PID FROM QUAD4 WHERE PID=3;

  EID    PID
-----  -----
    2      3
    3      3
```

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The UPDATE Commands

```
ICE> SELECT COLUMNS(STRING) 3 FROM KGG;
MATRIX KGG, REAL DOUBLE PRECISION  5 ROWS, 5 COLUMNS
----------------------------------------------------------
COLUMN 1, STRING 1 - BEGINS IN ROW 2
 4.00000E+00   5.00000E+00   6.00000E+00

ICE> UPDATE MATRIX KGG SET 3 TO
  2      VALUES AT ROW 3 (20.0);

....  1 COLUMN UPDATED

ICE> SELECT COLUMNS(STRING) 3 FROM KGG;
MATRIX KGG, REAL DOUBLE PRECISION  5 ROWS, 5 COLUMNS
----------------------------------------------------------
COLUMN 1, STRING 1 - BEGINS IN ROW 2
 4.00000E+00   2.00000E+01   6.00000E+00
```

```
ICE> UPDATE MATRIX KGG SET 5 TO
  1>      VALUES AT 1 (5.0);
ERR> CANNOT UPDATE MATRIX KGG AT COLUMN 5 ROW 1
```

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The ALTER Command

```
ICE> ALTER GRID ADD ( DIST,RSP );
.... ATTRIBUTE DIST ADDED TO GRID
ICE> DESCRIBE GRID;

.... ATTRIBUTE  TYPE    LEN
.... ---------  ----  -----
....       GID   INT      1
....       CID   INT      1
....         X   RSP      1
....         Y   RSP      1
....         Z   RSP      1
....      DIST   RSP      1
```

UNIVERSAL ANALYTICS, INC.

Removing Data from CADDB

- **PURGE { RELATION | MATRIX | UNSTRUCTURED }** entity_name;

- **DELETE FROM RELATION** relation_name [<WHERE_part>];

- **DELETE FROM MATRIX** matrix_name (column_list);

The DELETE Commands

```
ICE> DELETE FROM RELATION GRID
  2>       WHERE Y = 0.0;
```

```
ICE> DELETE FROM RELATION PSHELL
  2>      WHERE PID = ( SELECT PID FROM QUAD4
  3>                          WHERE EID = 2 );

ICE> SELECT * FROM PSHELL;
  PID    MID             T
-----  -----  ------------
    1    101   1.00000E-01
    3    301   3.00000E-01
```

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The DELETE Commands

```
ICE> DELETE FROM MATRIX KGG (1,3,5);

....  3 COLUMNS DELETED FROM KGG

ICE> SELECT COLUMNS(FULL) * FROM KGG;
MATRIX KGG, REAL DOUBLE PRECISION  5 ROWS,  2 COLUMNS
----------------------------------------------------------
COLUMN 1, ROW 1
 2.00000E+00   3.00000E+00   4.00000E+00
----------------------------------------------------------
COLUMN 2, ROW 3
 6.00000E+00   7.00000E+00   8.00000E+00
```

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File Environment Commands

- SET{ SCRIPT | ARCHIVE |
  REPORT | INTERFACE } TO "file_name";
- SCRIPT OFF;
- SCRIPT ON [REPLAY];
- { ARCHIVE | REPORT | INTERFACE }
  { ON | OFF };
- INTERFACE FORMAT "format_specifier";

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The SCRIPT FILE

```
...
...        CQL Command Sequence 1
...
SCRIPT OFF;
...
...        CQL Command Sequence 2
...
SCRIPT OFF;
```

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The SCRIPT FILE

```
ICE> SET SCRIPT TO "MYCOM.DAT";
ICE> ...
ICE> ...              Command Sequence 1 is Executed
ICE> ...
ICE> Commands are Entered by the User at the Terminal
ICE> SCRIPT ON;
ICE> ...
ICE> ...              Command Sequence 2 is Executed
ICE> ...
ICE> Commands are Entered by the User at the Terminal
ICE> SCRIPT ON;
ICE> ...ERROR - SCRIPT FILE EXHAUSTED
ICE> SCRIPT ON REPLAY;
ICE> ...
ICE> ...              Command Sequence 1 is Replayed
ICE> ...
ICE> Commands are Entered by the User at the Terminal
```

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Report Generation – 1

- **SET** < page_option_list >
- <page_option_term > → { **LINEWIDTH** n |
  PAGELENGTH n |
  INTWIDTH n |
  FLOATWIDTH n }

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Report Generation — 2

- **SET UNDERLINE** "underline_character";
- **SET { HEADER | FOOTER }** "title_line"
  [<justification>]
  [DATE] [PAGE];
- **SET BREAK ON** attribute_name
  [SKIP n] [PAGE];

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Report Generation – 3

- **SET COLUMN** attribute_name <column_options>;

- <column_options> → [<heading_info>]
  [<format_info>]
  [<justification >]
  [**TEMP**] [**CLEAR**]

- <heading_info> → **LABEL** { "string" |
  "multi_line_title" };

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Report Generation — 4

- <justification> → { LEFT |
  RIGHT |
  CENTER };

- <format_info> → FORMAT
  "{ Iw | Fw.d |
  Ew.d | Dw.d |
  Aw | Gw.d }";

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The SET COLUMN Command

```
ICE> SET COLUMN EID HEADING "ELEMENT/ID NUMBER"
ICE> SET COLUMN PID HEADING "PSHELL ID"
ICE> SELECT * FROM QUAD4;

  ELEMENT
ID NUMBER  PSHELL ID     G1     G2     G3     G4
---------  ---------  -----  -----  -----  -----
        1          1      1      2      7      6
        2          2      2      3      8      7
        3          1      3      4      9      8
        4          2      4      5     10      9
```

The SET COLUMN Command

```
ICE> SET COLUMN GID LABEL "GRID ID";
ICE> SET COLUMN X FORMAT "F9.5";
ICE> SET COLUMN Y FORMAT "F9.5";
ICE> SET UNDERLINE "=";
ICE> SELECT * FROM GRID WHERE X=4.0;

GRID ID    CID          X          Y            Z
=======  =====  =========  =========  ===========
      5      0    4.00000    1.00000  0.00000E+00
     10      0    4.00000    0.0      0.00000E+00
```

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Page Headers, Footers and Breaks

```
ICE> SET HEADER "GRID POINTS ALONG STATION X=4.0" PAGE;
ICE> SET FOOTER "ASTROS DESIGN SAMPLE" CENTER;
ICE> SELECT * FROM GRID WHERE X=4.0;

          GRID POINTS ALONG STATION X=4.0       PAGE   1

 GRID
   ID    CID          X          Y             Z
 -----  -----  ---------  ---------  ------------
     5      0    4.00000    1.00000   0.00000E+00
    10      0    4.00000   0.0        0.00000E+00

            ASTROS DESIGN SAMPLE                 29-Feb-88
```

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Page Headers, Footers and Breaks

```
ICE> SET BREAK ON PID SKIP 1;
ICE> SELECT * FROM QUAD4 GROUP BY PID;

  EID    PID     G1     G2     G3     G4
-----  -----  -----  -----  -----  -----
    1      1      1      2      7      6
    3      1      3      4      9      8

    2      2      2      3      8      7
    4      2      4      5     10      9
```

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CADDB Security

- **SET PASSWORDS** <password_list>
- <password_term> → { **READ**=pass |
  WRITE=pass |
  MODIFY=pass |
  DELETE=pass }
- **USE PASSWORDS** <password_list>

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Utility Functions

- **SET TOLERANCE** value [**PERCENT**];
- **HELP** [command_name [command_part]];
- **SHOW** [<variable_class_list>];
- <variable_class> → { **FILES** | **COLUMN** | **PAGE** }

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Conclusions

- ICE has Great Potential for Improving the Design Process
- ICE Allows Nearly Unlimited Querying of ASTROS Data
- ICE Can be Used in Conjunction with Other Programs
- ICE Can Increase the Understanding of Design Results

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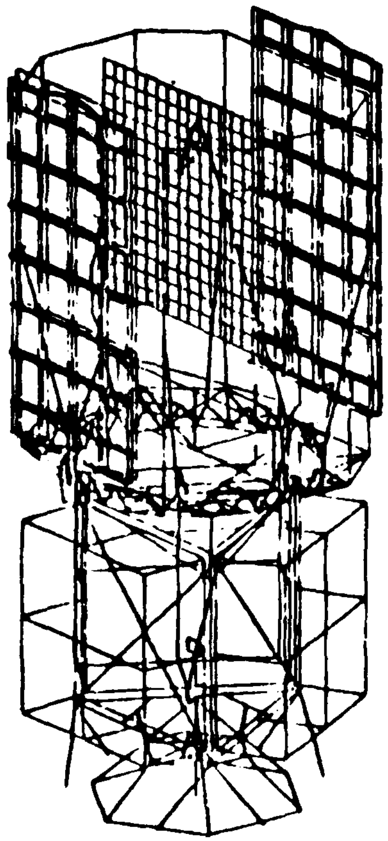
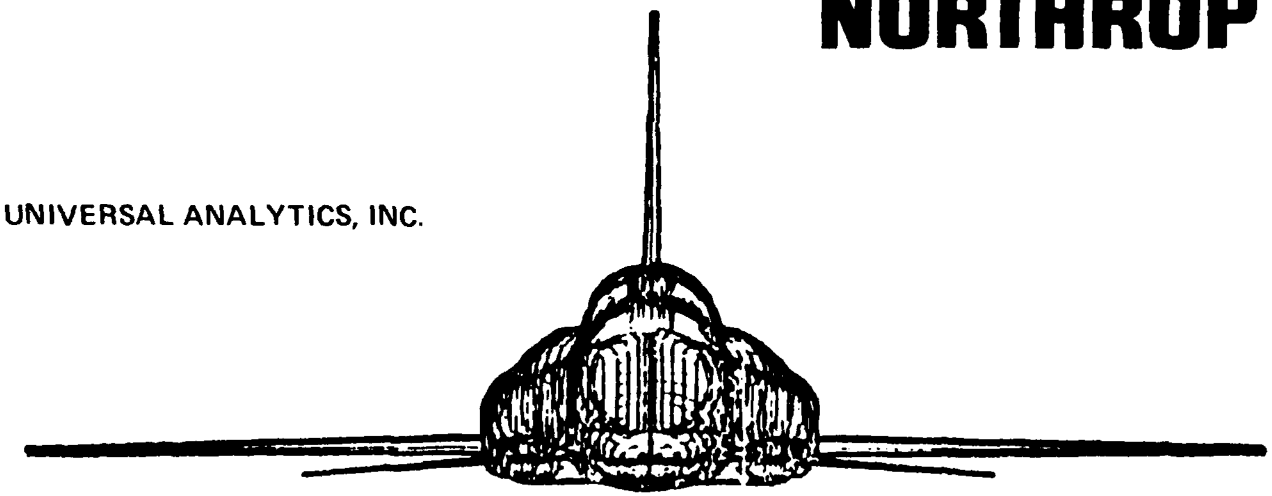
AUTOMATED STRENGTH-AEROELASTIC DESIGN OF AEROSPACE STRUCTURES

NORTHROP

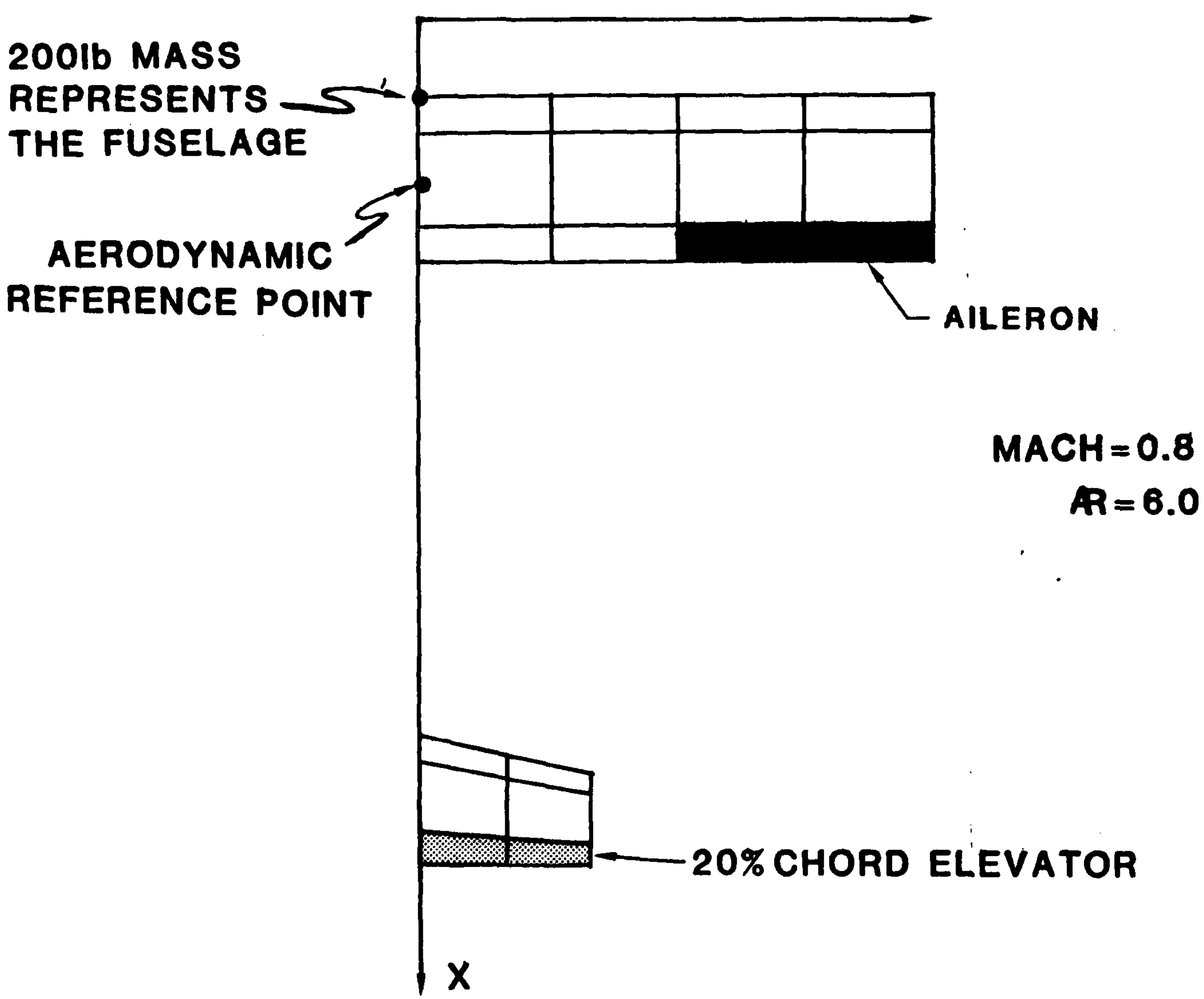
UNIVERSAL ANALYTICS, INC.



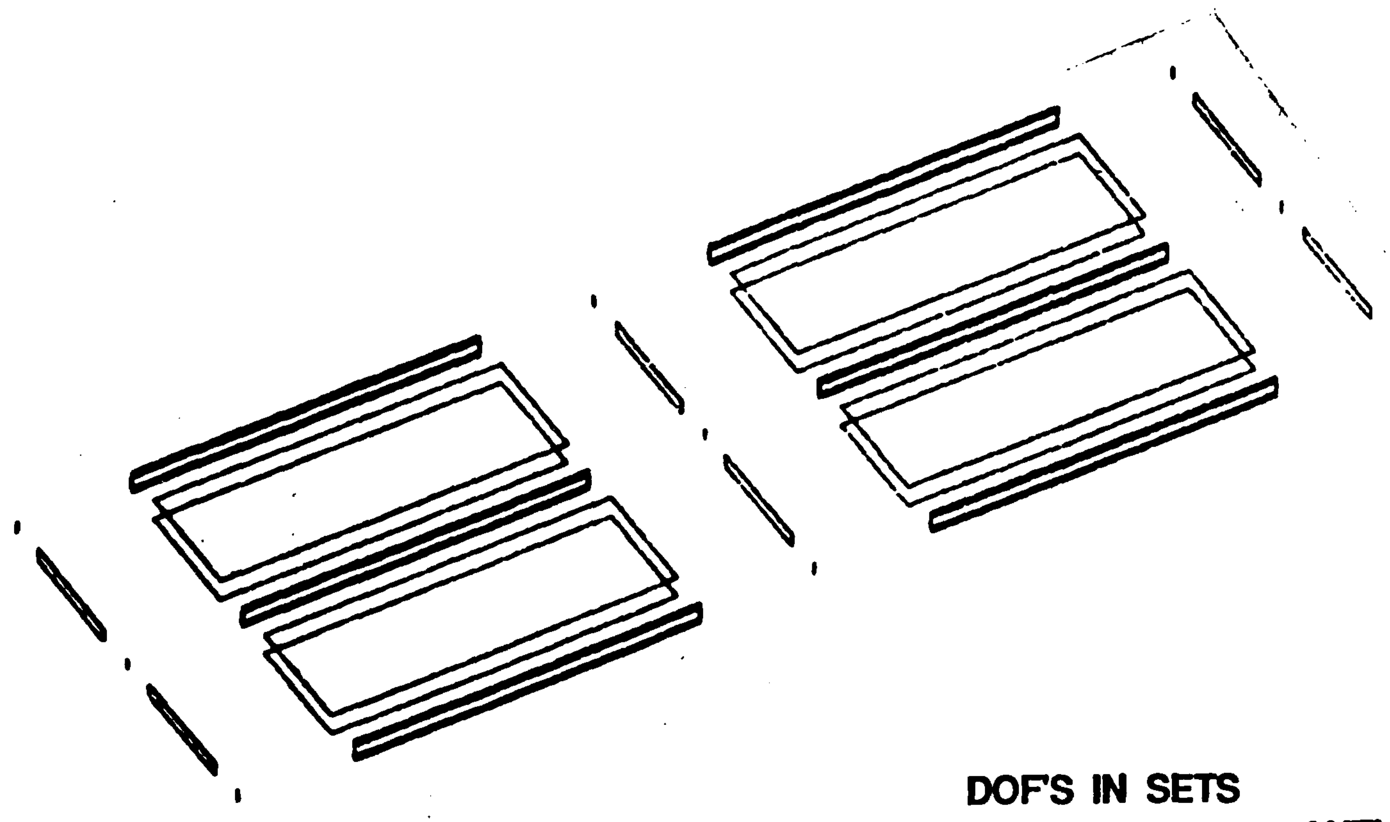


Applications

AERODYNAMIC MODEL FOR RECTANGULAR WING



Rectangular Wing Box Model



	ELEMENTS
ROD	9
SHEAR	12
QUAD MEMBRANE	6
CONM2	1
TOTAL	28

DOF'S IN SETS

	SYMMETRIC	ANTI SYMMETRIC
MPC	4	6
SPC	64	71
SOLUTION	44	36
REFERENCE	2	1
TOTAL	114	114

10-13-87-05-EJ

Aeroelastic Design Conditions For The Rectangular Wing

Constraint	Case			
	A	B	C	D
Maximum Tip Rotation (Degs)	1.0	1.0	---	1.0
Maximum Lift Effectiveness	---	1.60	---	1.6
Minimum Aileron Effectiveness	---	---	0.30	0.30

Stress Constraints were Applied Cases A, B and D :

$\sigma_T \leq 20$ ksi

$\sigma_U \leq 15$ ksi

$T_{xy} \leq 12$ ksi

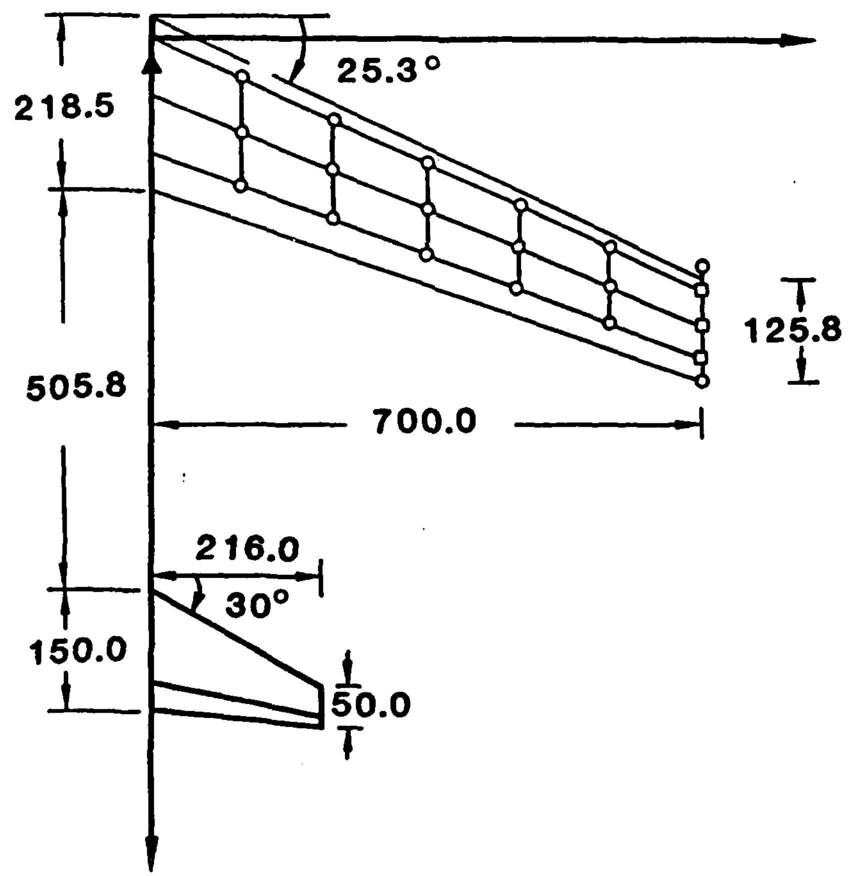
10-15-87-01-EJ

Design Results for the Rectangular Wing

Parameter	Case			
	A	B	C	D
Inboard Thickness	0.135	0.174	0.106	0.174
Outboard Thickness	0.082	0.058	0.082	0.058
Weight	26.00	27.68	22.57	27.68
Tip Rotation	1.00	1.00	1.78	1.00
Lift Effectiveness	1.843	1.60	2.22	1.60
Aileron Effectiveness	0.312	0.308	0.300	0.308
Trimmed Angle of Attack	1.05	1.26	0.83	1.26
Trimmed Elevator Setting	-1.26	-1.56	-0.99	-1.56

10-15-87-01-EJ

Swept Wing Example Model Geometry



Design Requirements for the Swept Wing

- Boundary Condition 1 - Cantilevered at Root
  - Flutter Speed > 530 KEAS, M = 0.8, Sea Level
  - First Modal Frequency ≥ 1.5 Hz
- Boundary Condition 2 - Unrestrained
  - Trimmed Symmetric 4g Pullup, M = 1.25, 25000 Ft
  - Stress Limits in Cover Skins

$\sigma_t \leq 60$ Ksi

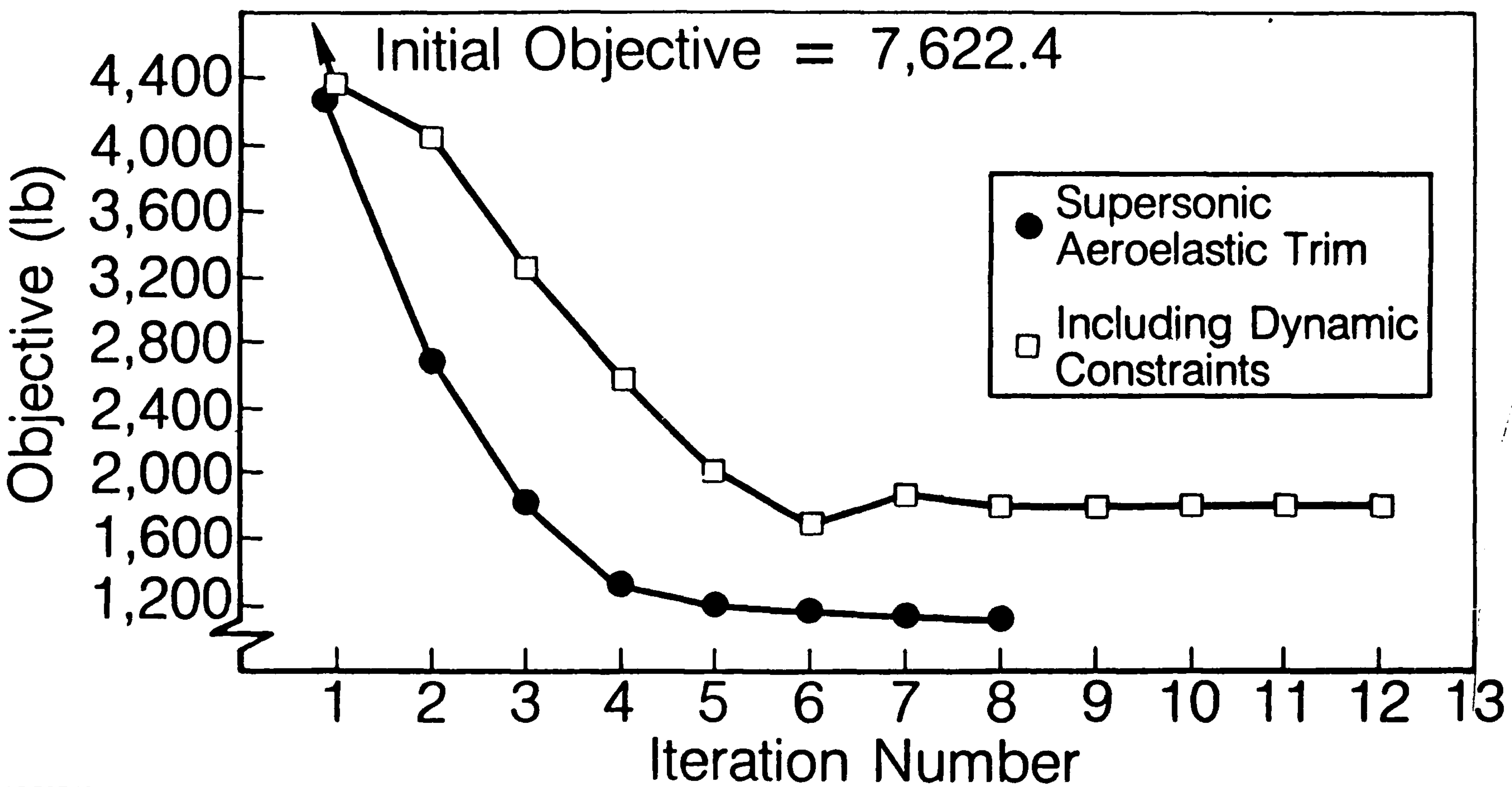
$\sigma_c \leq 50$ Ksi

$\tau_{xy} \leq 30$ Ksi

- 13 Design Variables

  60 Constraints

Swept Wing Example — Iteration History



87-50540
3Q NS

Intermediate Complexity Wing Model Geometry

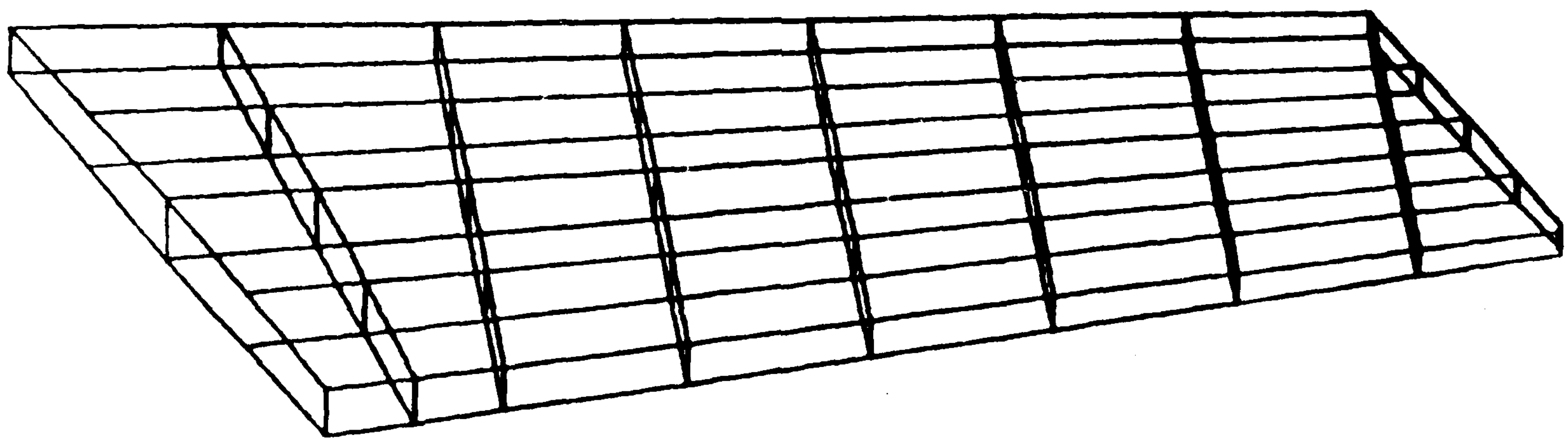
No. of Nodes
88

No. of Elements

39	Rods
55	Shear Panels
62	Quadrilateral Membrane
2	Triangular Membrane
158	Total

No. of DOF's

294	Constrained
234	Unconstrained
528	Total



Design Requirements For Intermediate Complexity Wing

- Displacement Constraints
  - All out of plane tip displacements are limited to ± 10 inches

- Isotropic Material

$E = 10.5 \times 10^6$ psi $\qquad \rho = 0.10$ lb/in^3

$\nu = 0.30$ $\qquad t_{min} = 0.04$ in

$\sigma_T \leq 45$ ksi

$\sigma_C \leq 55$ ksi

$\tau_{xy} \leq 45$ ksi

- Orthotropic Material

$E_1 = 19.9 \times 10^6$ psi $\qquad \nu_{12} = 0.32$ $\qquad \rho = 0.055$ lb/in^3

$E_2 = 1.5 \times 10^6$ psi $\qquad G_{12} = 0.85 \times 10^6$ psi $\qquad t_{min} = 0.04$ in

$\varepsilon_T \leq 4500\ \mu$

$\varepsilon_C \leq 3200\ \mu$

Design Cases For Intermediate Complexity Wing

- Problem 1

  Strength Constraints Under Two Static Loads

  20 Displacement Constraints
  316 Von Mises Stress Constraints

  Isotropic Material Properties

  Upper/Lower Surfaces Linked - 57 Design Variables

- Problem 2

  Strength Constraints Under Two Static Loads

  20 Displacement Constraints
  110 Von Mises Stress Constraints
  256 Principal Strain Constraints

  Orthotropic Material Properites

  Upper/Lower Surfaces Linked For Each Ply Orientation

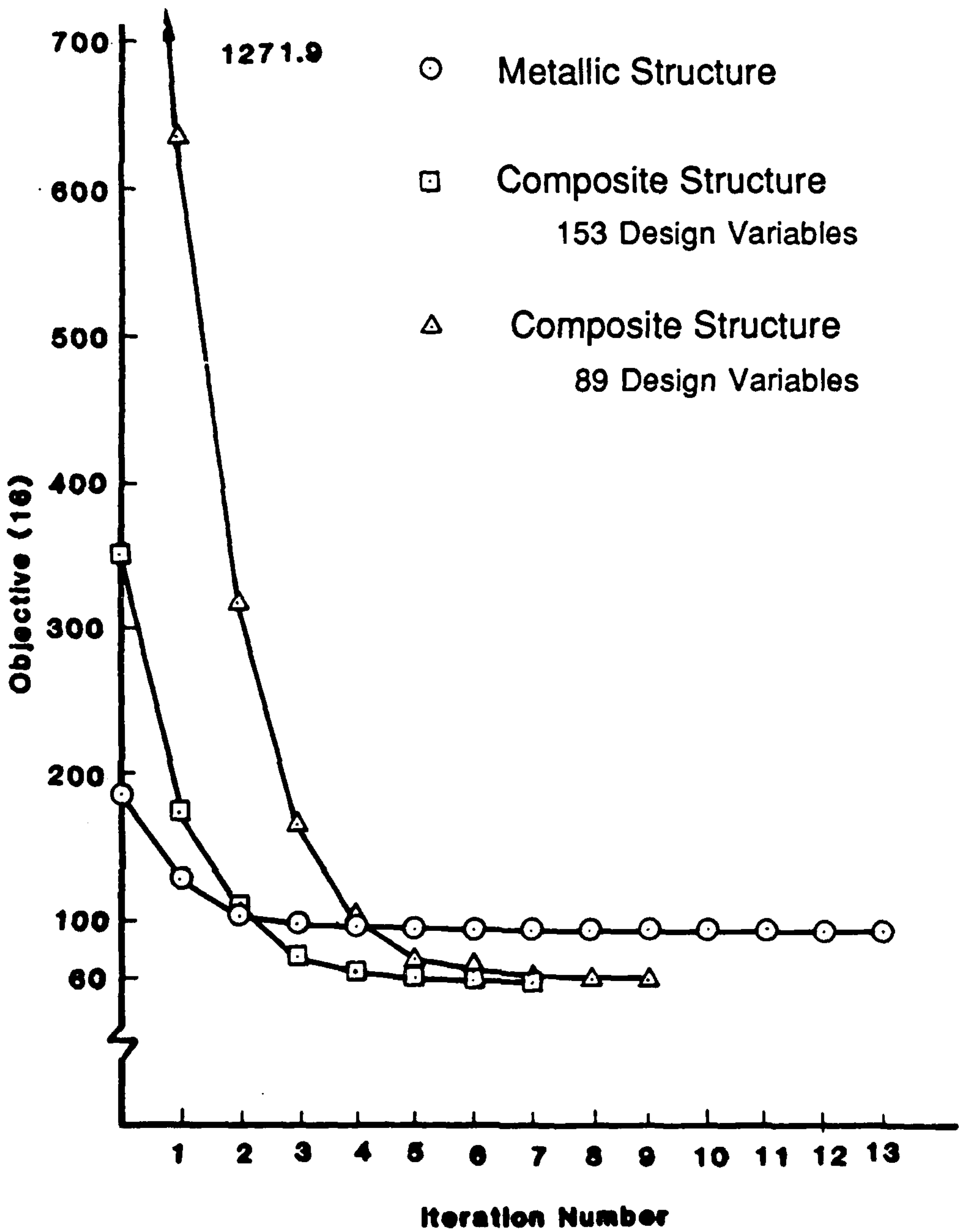
  153 Design Variables

- Problem 3 - Same as Problem 2 Except:

  Upper/Lower Surfaces Linked For Each Bay For Each Ply

  89 Design Variables

Intermediate Complexity Wing Iteration Histories



Design Requirements for the Intermediate Complexity Wing

- **Flutter Constraints**

  $V_f \leq 925$ knots
  $\rho = .0023769$ slugs/ft^3
  $M = 0.80$

- **Isotropic Material in Substructure**

  $E = 10.5 \times 10^6$ psi
  $\nu = 0.30$

  $\rho = 0.10$ lb/in^3
  $t_{min} = 0.04$ in

  $\sigma_T \leq 45$ ksi
  $\sigma_C \leq 55$ ksi
  $\tau_{xy} \leq 45$ ksi

- **Orthotropic Material in Skins**

  $E_1 = 18.5 \quad 10^6$ psi
  $E_2 = 1.6 \times 10^6$ psi

  $\nu_{12} = 0.25$
  $G_{12} = 0.65 \times 10^6$ psi

  $\rho = 0.055$ lb/in^3
  $t_{min} = 0.00525$ in

  $X_T = X_C = Y_T = Y_C = 1.15 \times 10^5$ psi
  $S \leq 1.0 \times 10^{15}$

Design Cases For Intermediate Complexity Wing

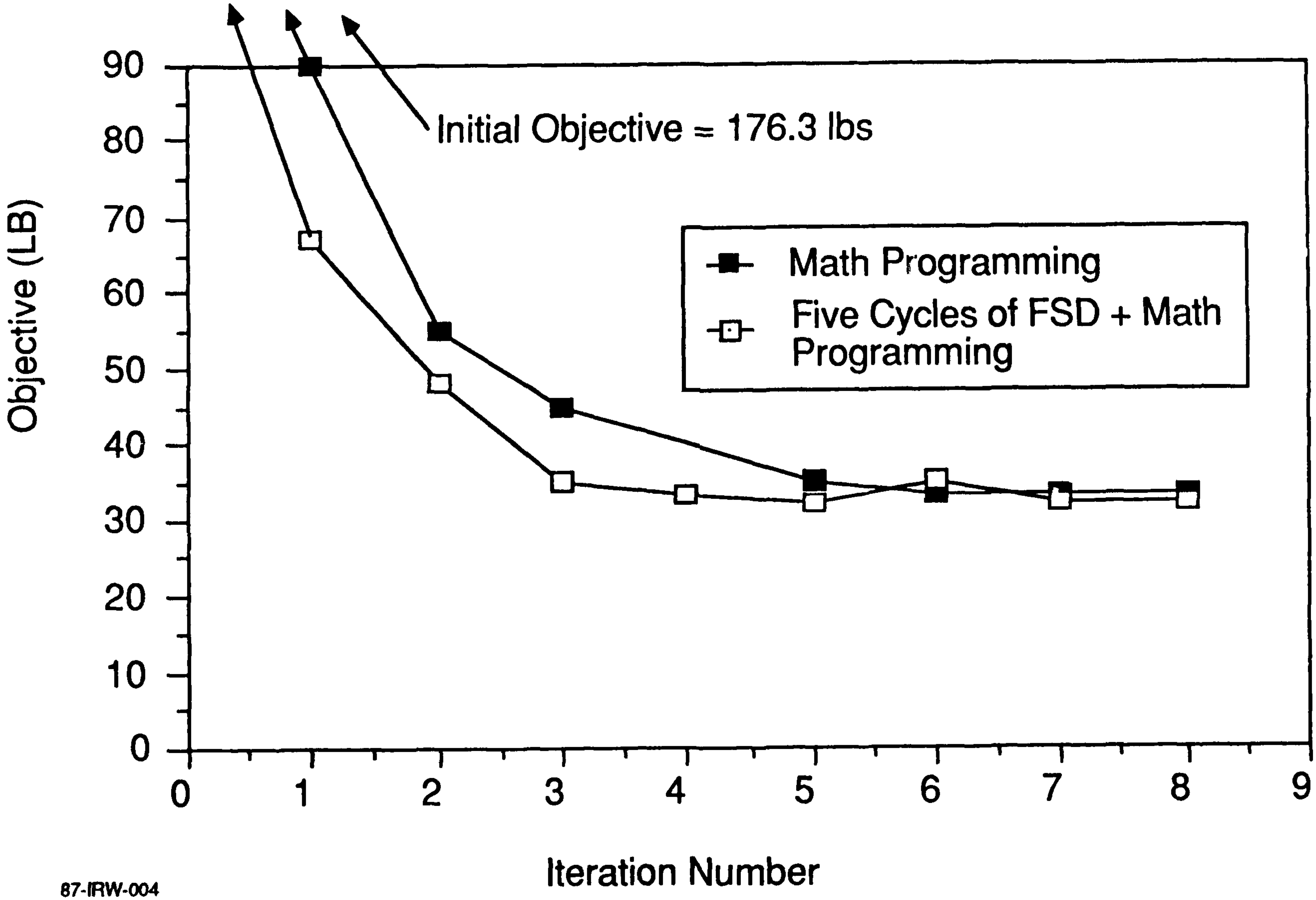
- Problem 1
  Strength Contraints Under Two Static Loads
    - 110 Von Mises Stress Constraints
    - 256 TSAI WU Constraints
  Upper/Lower Surfaces Linked For Each Ply Orientation
    - 153 Design Variables

- Problem 2 - Same as Problem 1 Except:
  Flutter Constraint is Imposed

- Problem 3 - Same as Problem 2 Except:
  Shape Functions Are Used
    - 22 Design Variables
    - Ribs and Posts not Designed
- Problem 4 - Same as Problem 3 Except:
  Flutter Contraint is Imposed

87-IRW-008

ICW Strength and Flutter Design - Iteration Histories

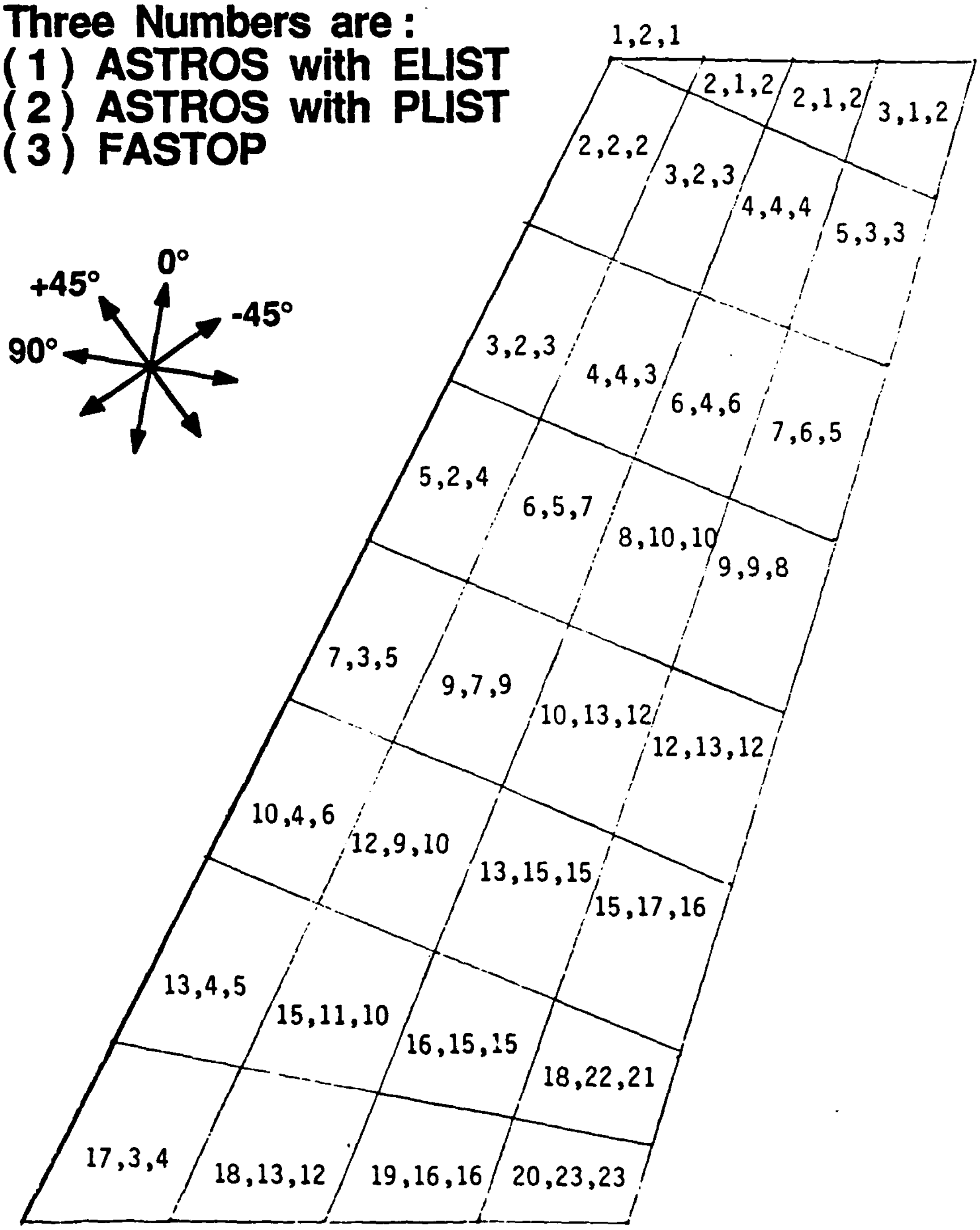


87-IRW-004

ICW Strength Design

Ply Counts for the 0° Laminate

Three Numbers are :
(1) ASTROS with ELIST
(2) ASTROS with PLIST
(3) FASTOP

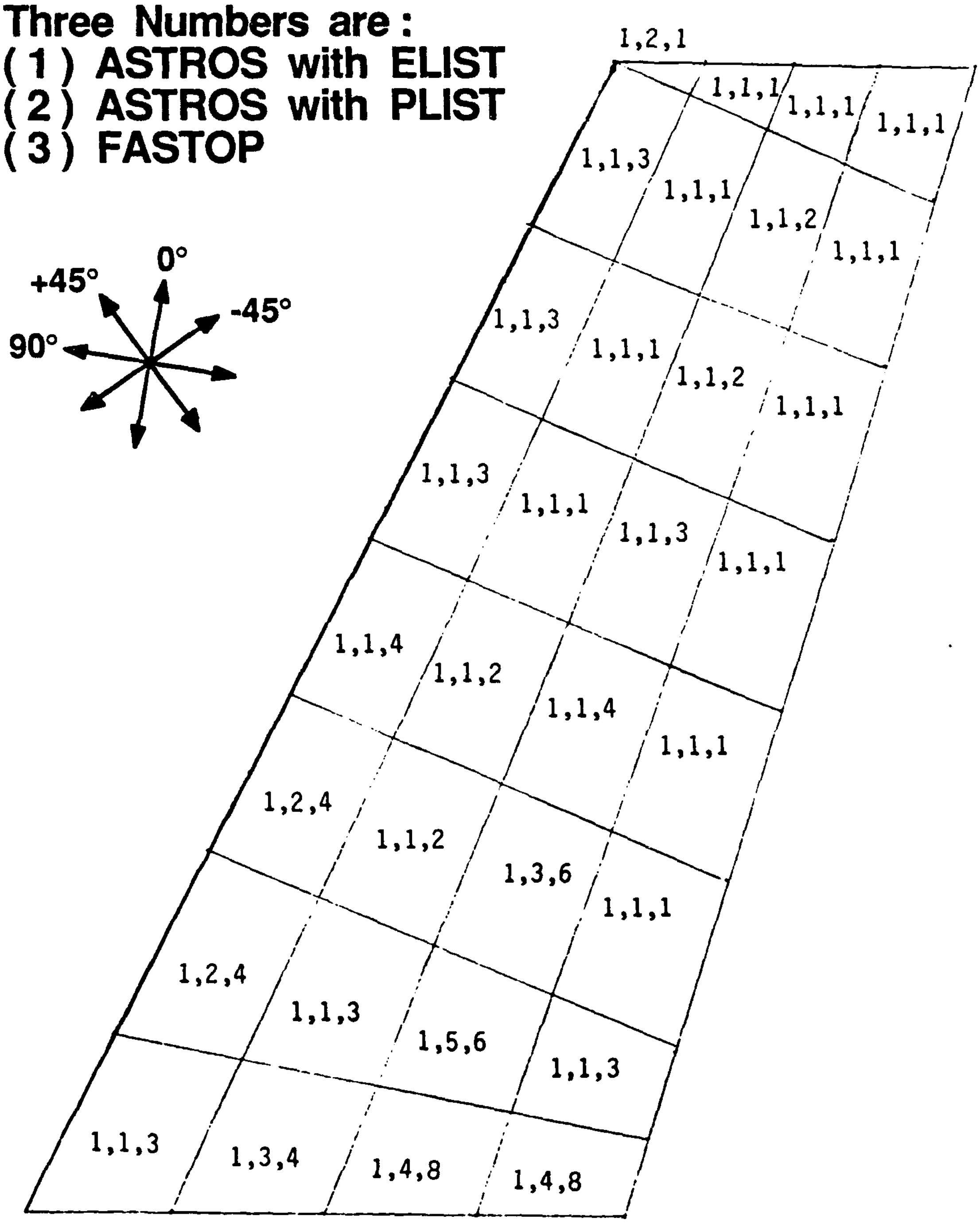


10-15-87-12-EJ

ICW Strength Design

Ply Counts for the +45° Laminate

Three Numbers are :
(1) ASTROS with ELIST
(2) ASTROS with PLIST
(3) FASTOP

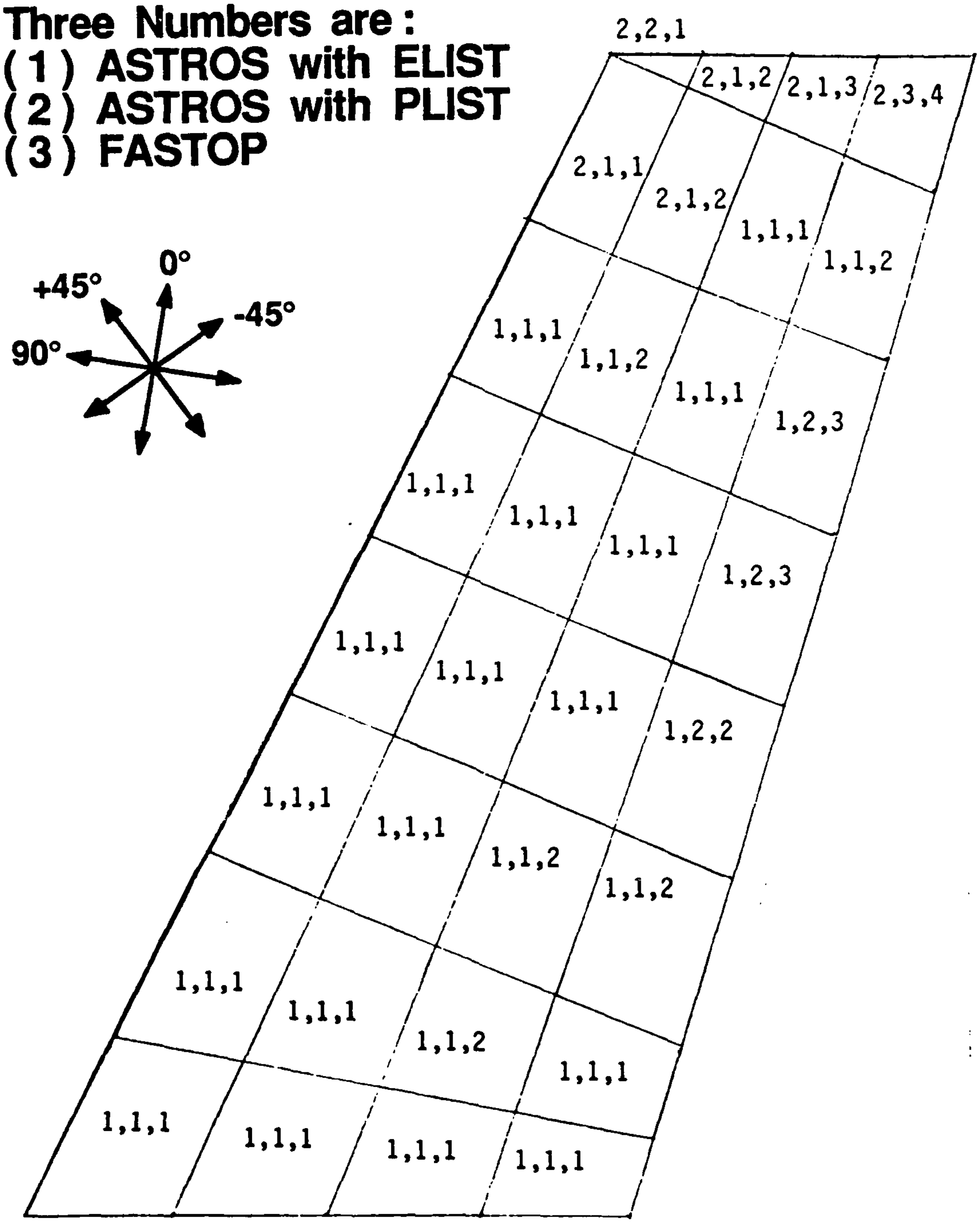


10-15-87-12-EJ

ICW Strength Design

Ply Counts for the -45° Laminate

Three Numbers are :
(1) ASTROS with ELIST
(2) ASTROS with PLIST
(3) FASTOP

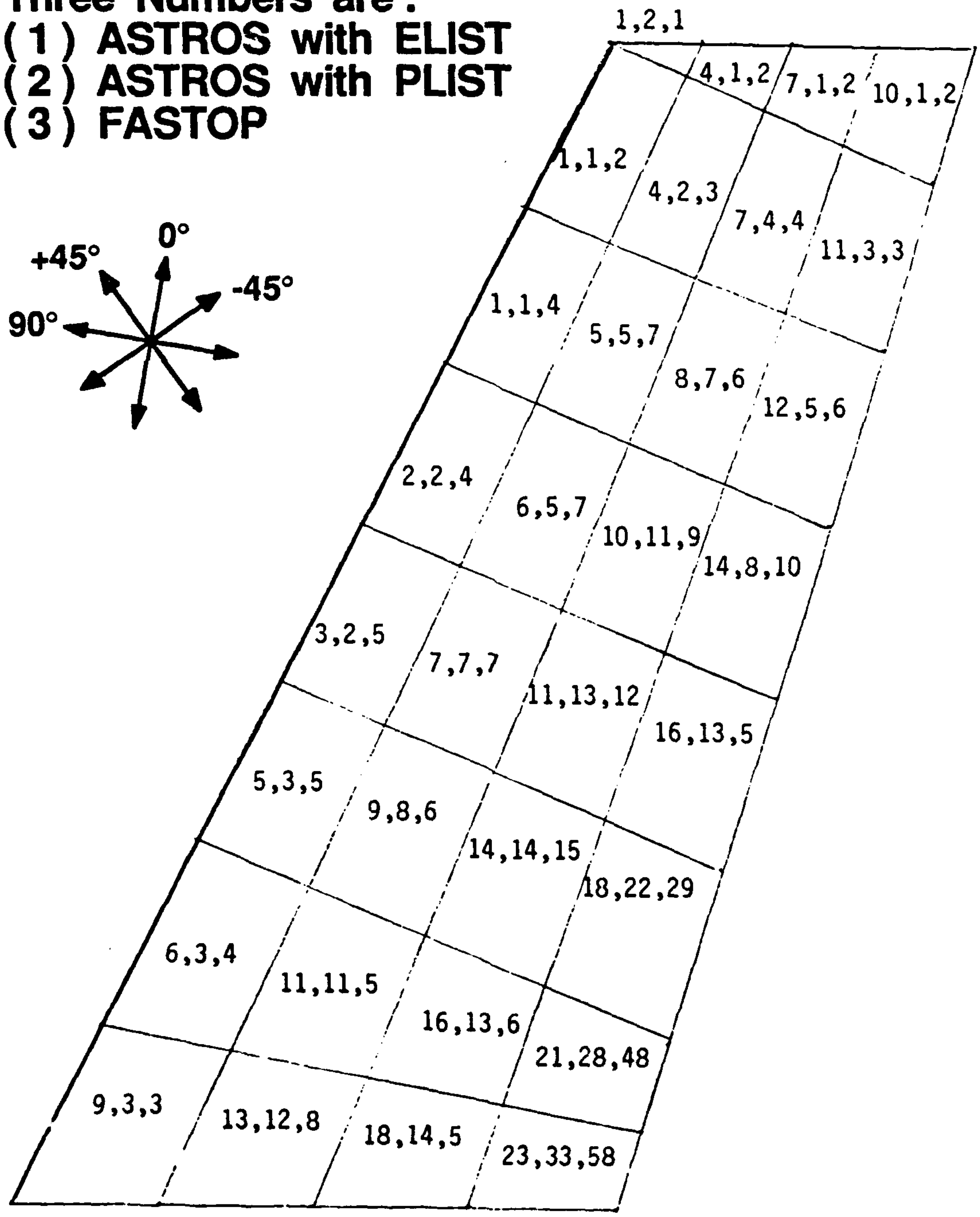


10-15-87-12-EJ

ICW Strength & Flutter Design

Ply Counts for the 0° Laminate

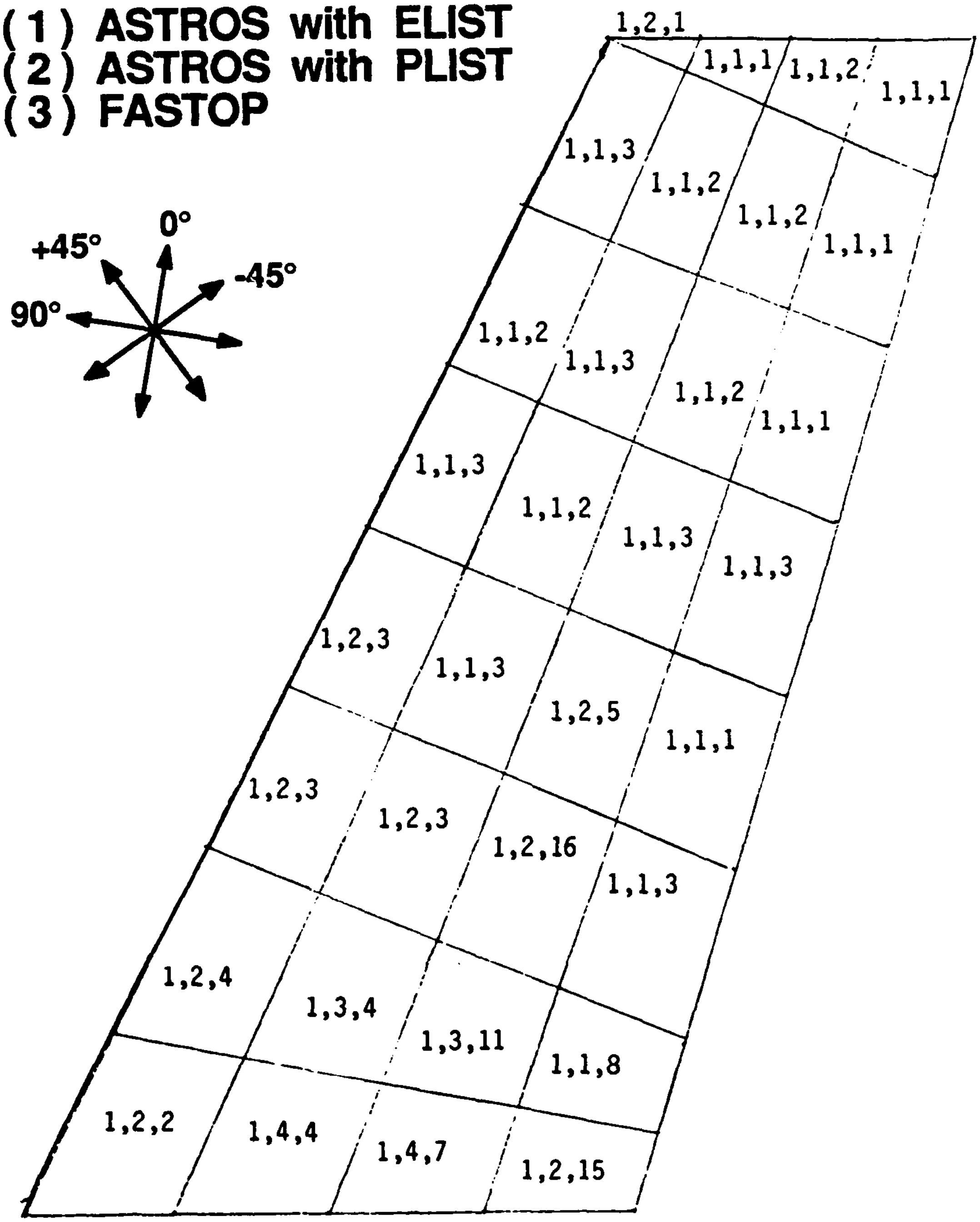
Three Numbers are:
(1) ASTROS with ELIST
(2) ASTROS with PLIST
(3) FASTOP



ICW Strength & Flutter Design

Ply Counts for the +45° Laminate

Three Numbers are:
(1) ASTROS with ELIST
(2) ASTROS with PLIST
(3) FASTOP

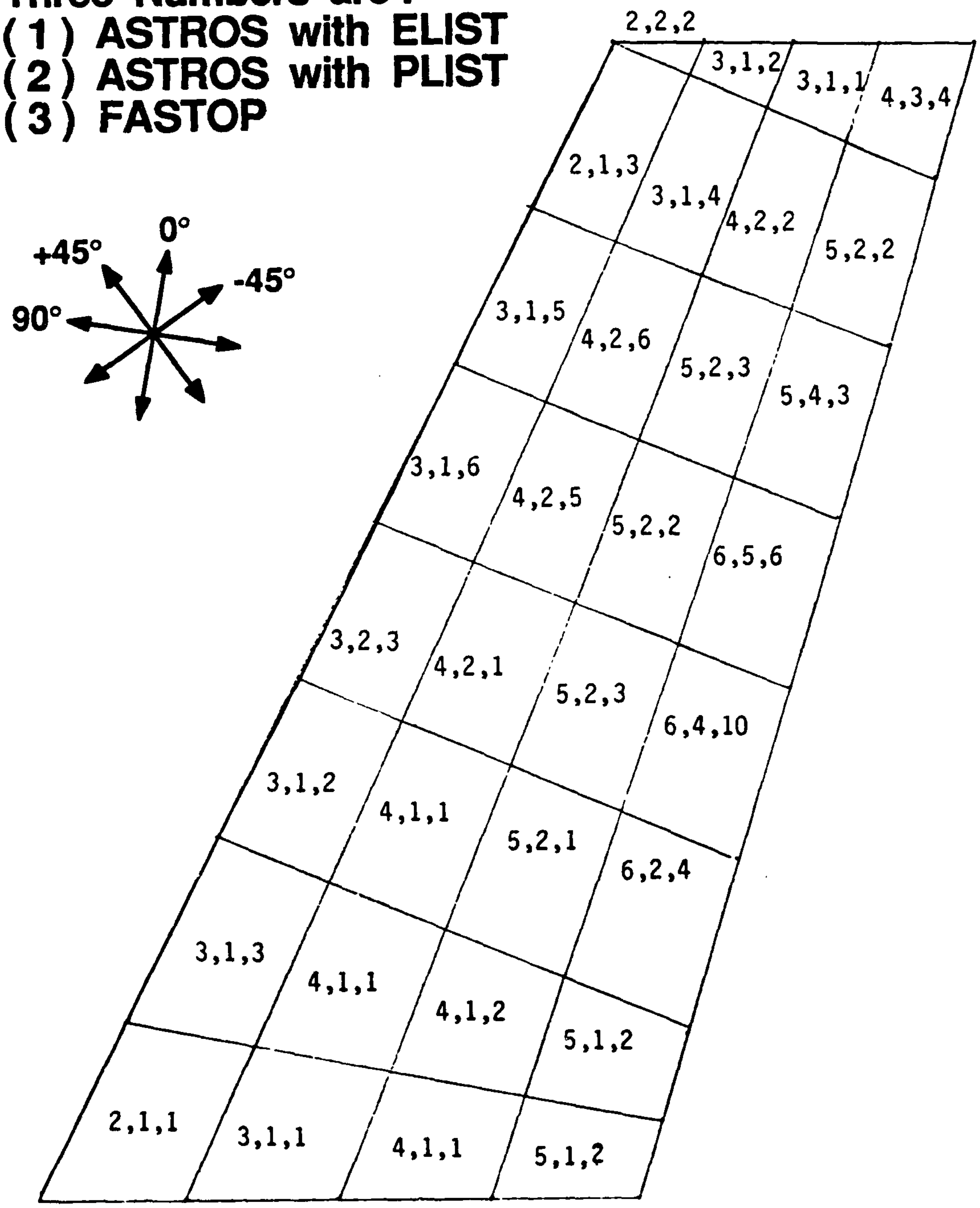


10-15-87-12-EJ

ICW Strength & Flutter Design

Ply Counts for the -45° Laminate

Three Numbers are:
(1) ASTROS with ELIST
(2) ASTROS with PLIST
(3) FASTOP

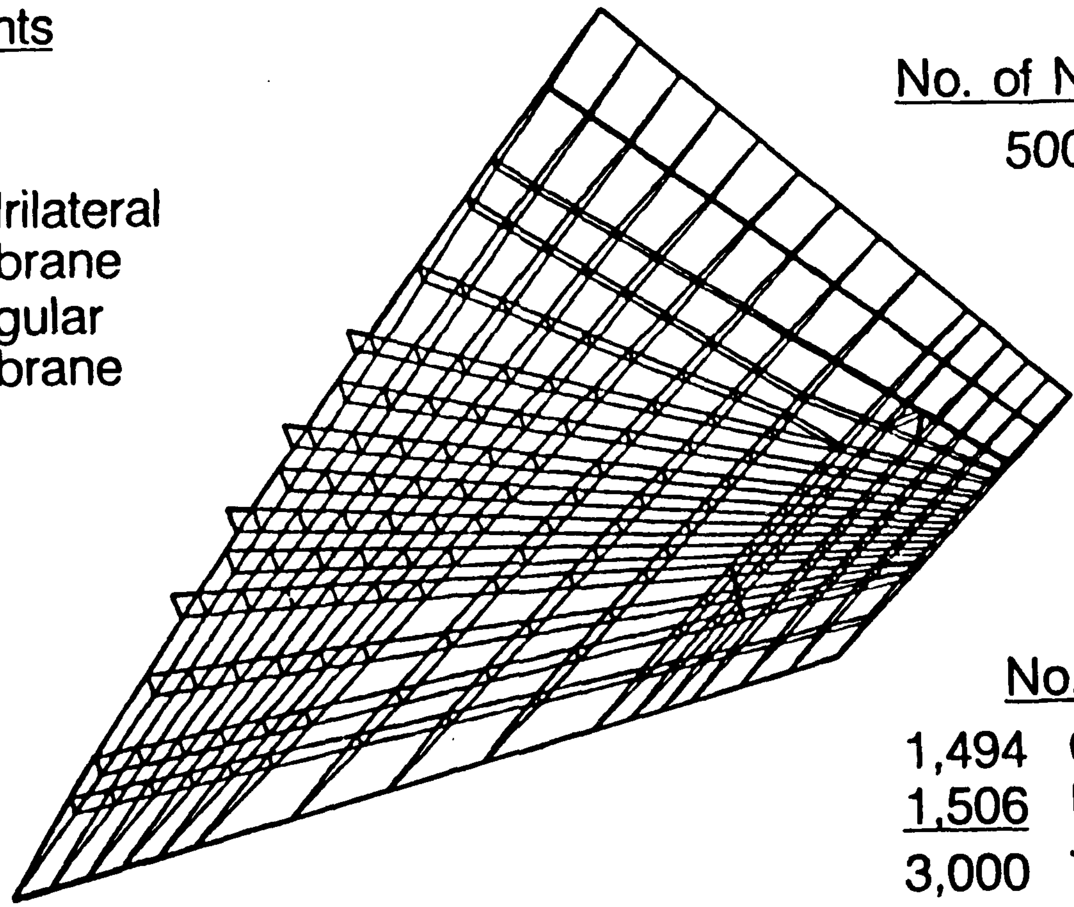


10-15-87-12-EJ

Structural Model of the N372-4 Fighter Wing

No. of Elements

8	Bars
468	Rods
1,570	Quadrilateral Membrane
67	Triangular Membrane
2,113	Total



No. of Nodes

500

No. of DOFs

1,494	Constrained
1,506	Unconstrained
3,000	Total

87-50539
3Q NS

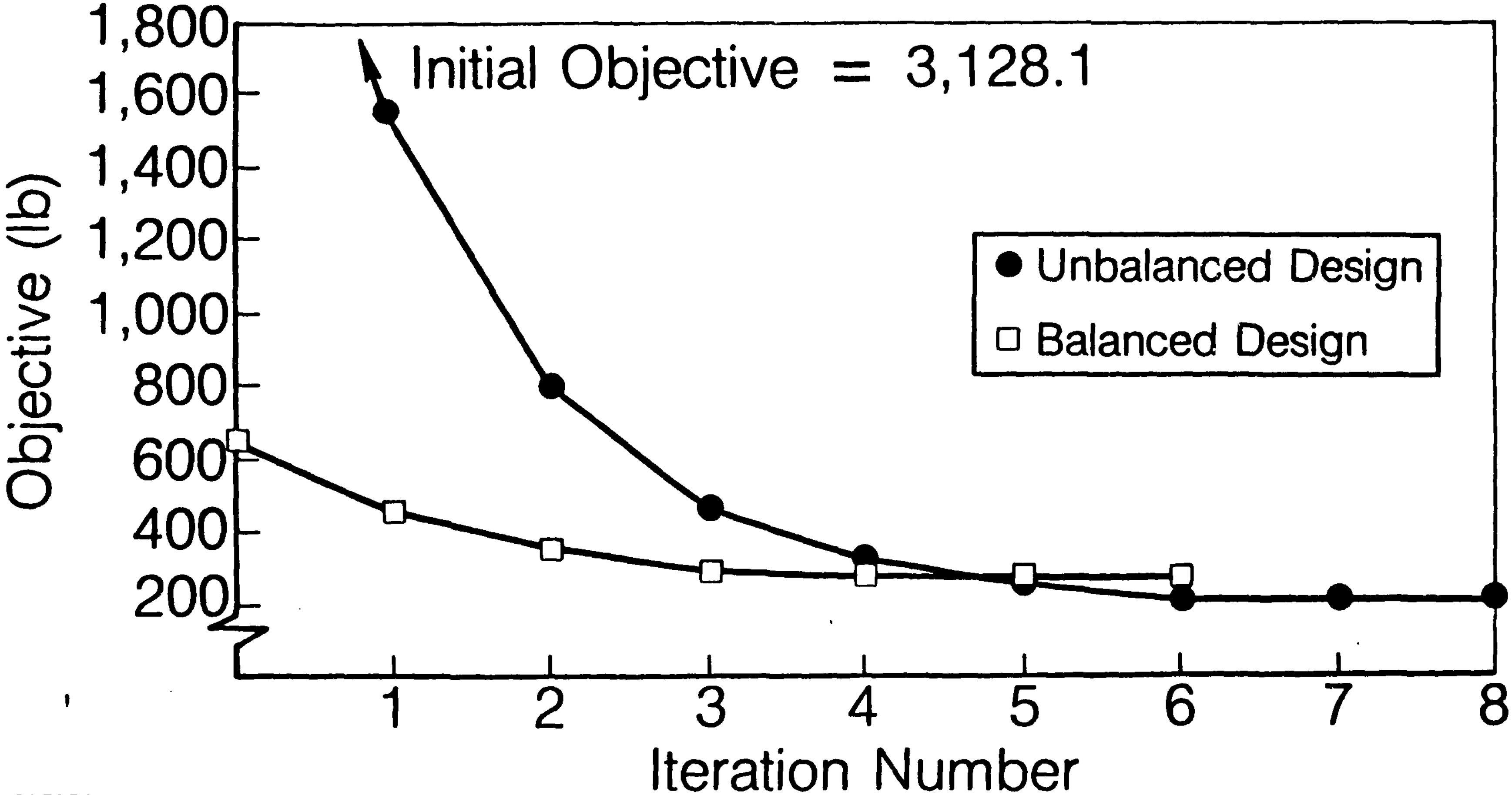
Design Requirements for the N372-4 Fighter Wing

- Single Boundary Condition - Cantilevered at Root
  - Static Load Equivalent to Rigid Air Load During a Symmetric 13.5 g Pullup, M = 2.5, 50000 Ft
  - Limits on Principal Strain of Torque Box Cover Skins

$$\varepsilon_1 , \varepsilon_2 \leq 0.0050$$

- Two Design Models
  - Unbalanced Laminate with 40 Design Variables
  - Balanced Laminate with 30 Design Variables
- 612 Strain Constraints

N372-4 Example — Iteration History



87-50541
3Q NS

ASTROS User Training Workshop
Problem Set Definitions

Problem Set #1: Space Truss
1–1: Modal Analysis using Guyan and Generalized Dynamic Reduction
1–2: Optimization for first two Natural Frequencies

Problem Set #2: Rectangular Wing
2–1: Static Analysis for Tip Load
2–2: Optimization for Stress constraints
2–3: Optimization for Stress constraints with Shape Functions
2–4: Static Analysis with Inertia Relief
2–5: Aeroelastic Trim for Wing in Straight, Level Flight
2–6: Aeroelastic Trim for Wing-Tail combination in Pull-up maneuver
2–7: Aeroelastic Analysis for Roll maneuver
2–8: Optimization for Stress and Tip Twist
2–9: Optimization for Stress, Tip Twist, and Lift Effectiveness
2–10: Optimization for Stress, Tip Twist, Lift and Aileron Effectiveness

Problem Set #3: Cantilvered Plate
3–1: Static and Modal Analyses
3–2: Transient Analysis
3–3: Subsonic and Supersonic Flutter Analysis

Problem Set #4: Swept Wing
4–1: Static Analysis for Gravity Load
4–2: Modal Analysis
4–3: Optimization for Stress and Frequency constraints
4–4: Subsonic Flutter Analysis
4–5: Supersonic Air Loads

Problem Set #5: Plane Frame
5–1: Optimization of 40 member Plane Frame for Stress and Displacement Constraints

Workshop Requirement is to complete 10 of the above 21 problems,
including at least one from each problem set.

ASTROS User Training Workshop
Problem Set #1: ACOSS Space Truss

The Active Control Of Space Structures (ACOSS) model II was developed by the Charles Stark Draper Laboratory. The structure consists of two subsystems: (1) the optical support structure and (2) the equipment section. The two are connected by springs at three points to allow vibration isolation (Figure 1–1). For this problem set disregard the equipment section at the base and consider the optical support structure fixed at the three connection points. The finite element model for this modified ACOSS II (Figure 1–2) has 33 nodes (90 degrees of freedom), 18 concentrated masses, and 113 rod elements made of graphite epoxy given (Table 1–1) with initial areas of 10.0 in^2 for the truss members. The grid points, masses, and element connectivities are given in attachment 1.

For this initial design the first three frequencies of the modified ACOSS II truss are: 1.21, 2.71, and 4.21 hz.

1–1) Verify the first three frequencies. Compare Guyan Reduction (omit degrees of freedom for nodes without concentrated masses) to Generalized Dynamic Reduction for reducing the size of the problem before applying Givens method.

1–2) Design the truss for minimum weight while raising the fundamental frequency to 2 hz and maintaining at least a 1 hz separation of the fundamental mode from the remaining modes. Use a minimum gage size of 0.01 in^2 for the truss elements. What are the first three frequencies and weight for the final design?

Young's Modulus	18.5×10^6 psi
Weight Density	0.055 lb/in^3

Table 1–1: Material Properties for Epoxy

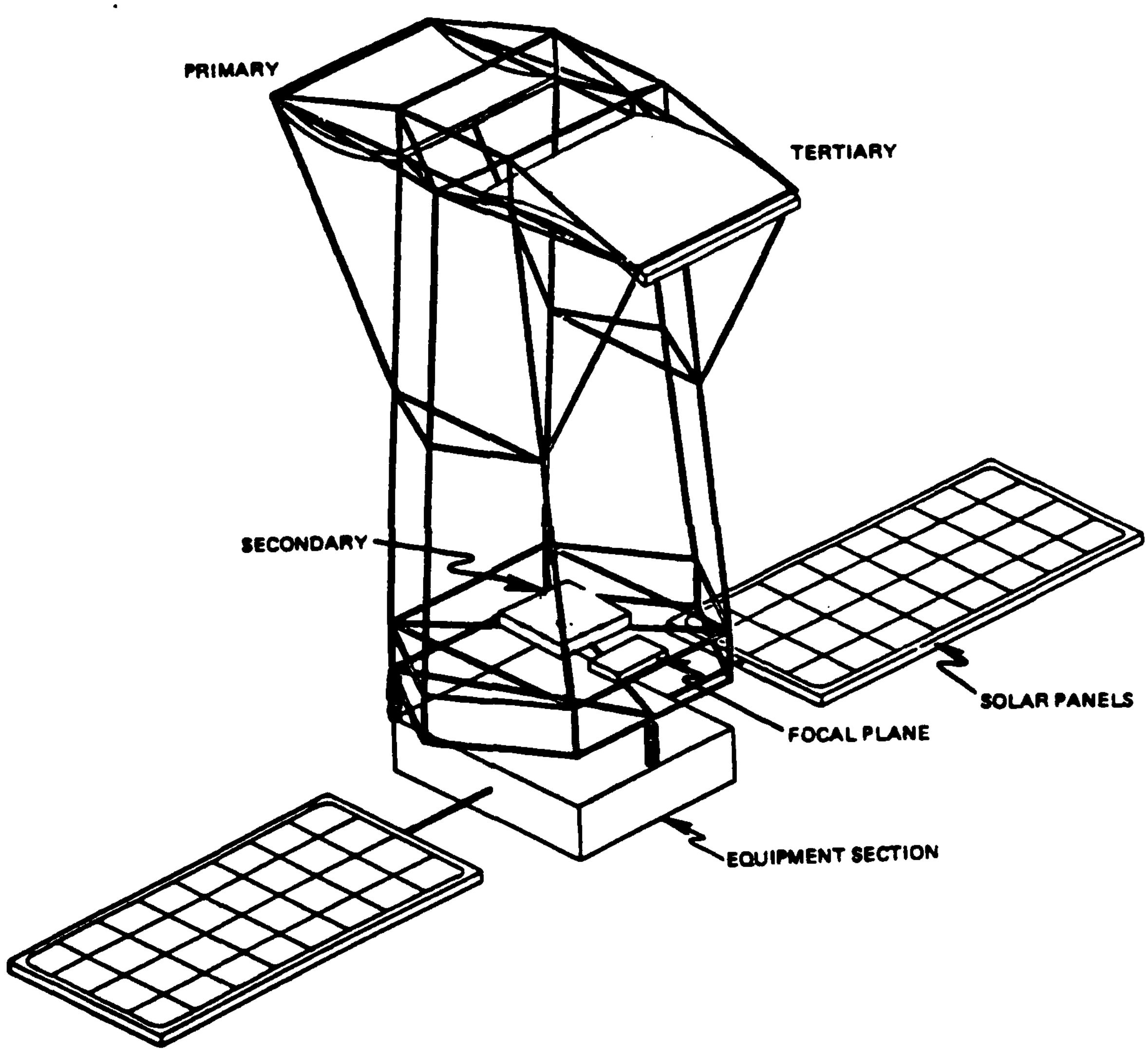


Figure 1–1: ACOSS Model II

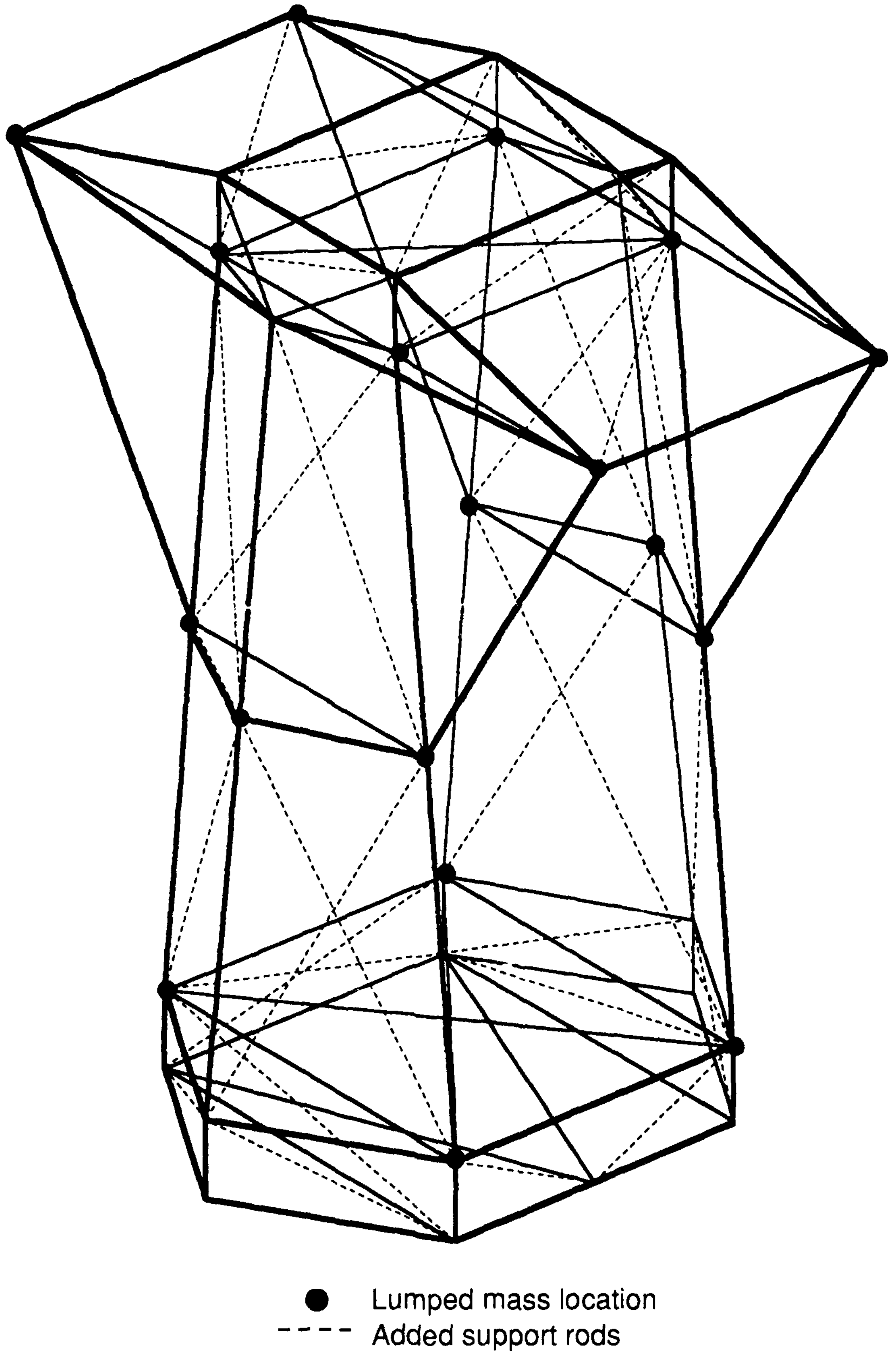


Figure 1–2: Finite Element Model for Modified ACOSS II

ASTROS User Training Workshop
Problem Set #2: Rectangular Wing

Structural Wing Box Model

A simple three-spar rectangular wing box is shown in Figure 2–1. The semi-span is 60" and the chord of the structural box (distance from front to rear spar) is 20". A 200 *lb* concentrated mass with a moment of inertia about the span axis of 22,500 $lb\text{-}in^2$ at the root of the front spar represents the fuselage mass. The wing is made of aluminum (material properties given in Table 2–1). The structural box is modeled using quadrilateral membrane elements for the cover skins, shear panels for the spars and ribs, and rod elements for the vertical posts (cross-sectional properties given in Table 2–2).

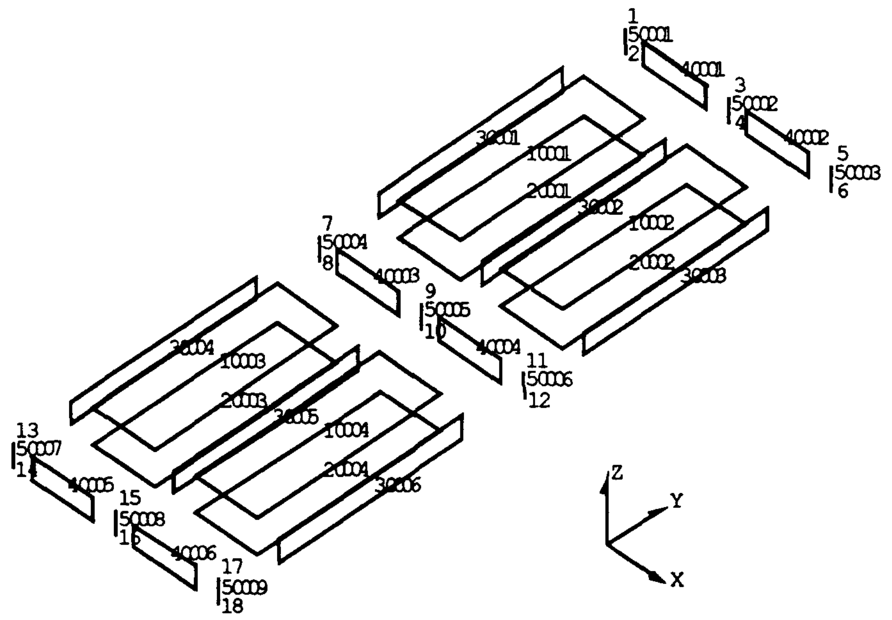


Figure 2–1: Rectangular Wing Structural Box

Young's Modulus	10.0 x 10^6 psi
Poisson's Ratio	0.3
Weight Density	0.1 lb/in^3
Tensile Strength	20.0 ksi
Compressive Strength	15.0 ksi
Shear Strength	12.0 ksi

Table 2–1: Material Properties for Aluminum

Membrane Thicknesses	0.20 in
Shear Thicknesses	0.05 in
Rod Areas	0.01 in^2

Table 2–2: Cross-Sectional Properties

2–1) Perform a static analysis of the wing when it is subjected to 100 *lb* load applied vertically at each of the six grid points at the wing tip. Consider the wing cantilevered at the root. Find the displacements of each grid point and the stresses in the cover skins.

Design Model

Use design variable linking to define four design variables that control the thicknesses of the eight cover skin membrane elements. Each design variable controls a group of two membrane elements, one fore and one aft, so the design variables control the (1) outboard upper skin, (2) outboard lower skin, (3) inboard upper skin, and (4) inboard lower skin. The spars, ribs, and posts remain fixed (are not designed).

2–2) Optimize the structural weight of the cover skins subject to stress constraints (Table 2–1) on the cover skins only . Find the optimum weight and design variable values for the boundary conidtion and static mechanical load given in problem 2–1.

2–3) Repeat problem 2–2 using shape function design variable linking. Use a constant thickness (initially 0.1") and a spanwise linear shape (initially 0.075" inboard and 0.025" outboard) for each of the upper and lower skins (4 design variables).

2–4) Perform a static analysis of the wing with inertia relief for the static load given in problem 2–1. Use multipoint constraints to rigidly connect the six grid points at the wing root to the root of the center spar midway between the top and bottom skins. The fuselage mass is associated with this "aerodynamic reference point" with an offset to locate it at the mid-surface of the front spar. Support the aerodynamic reference point in vertical translation (plunge) and find the displacements and accelerations.

Steady Aerodynamic Panel Model—Wing

The aerodynamic planform (Figure 2–2) for the wing has a 30" chord and 60" semi-span. The structural box's front and rear spar are located at the 13.33% and 80% chord locations, respectively. The aerodynamic box pattern shown in Figure 2–2 has four chordwise cuts at 0%, 20%, 80%, and 100% of the chord and five equal spanwise cuts. The airfoil shape given in Table 2–3 is for a symmetric airfloil (no camber) with a leading edge radius of 1.667%g. An aileron is defined by the two outboard trailing edge boxes of the wing.

2–5) Find the trimmed angle of attack, displacements, and accelerations for symmetric level flight (**1g** load factor) at Mach 0.8 and a dynamic pressure of 6.5 *psi*. Use the wing only and spline the aerodynamic boxes to the upper sufurface structural grid points. Compare the lift coefficient to the theoretical value for a thin airfoil wing.

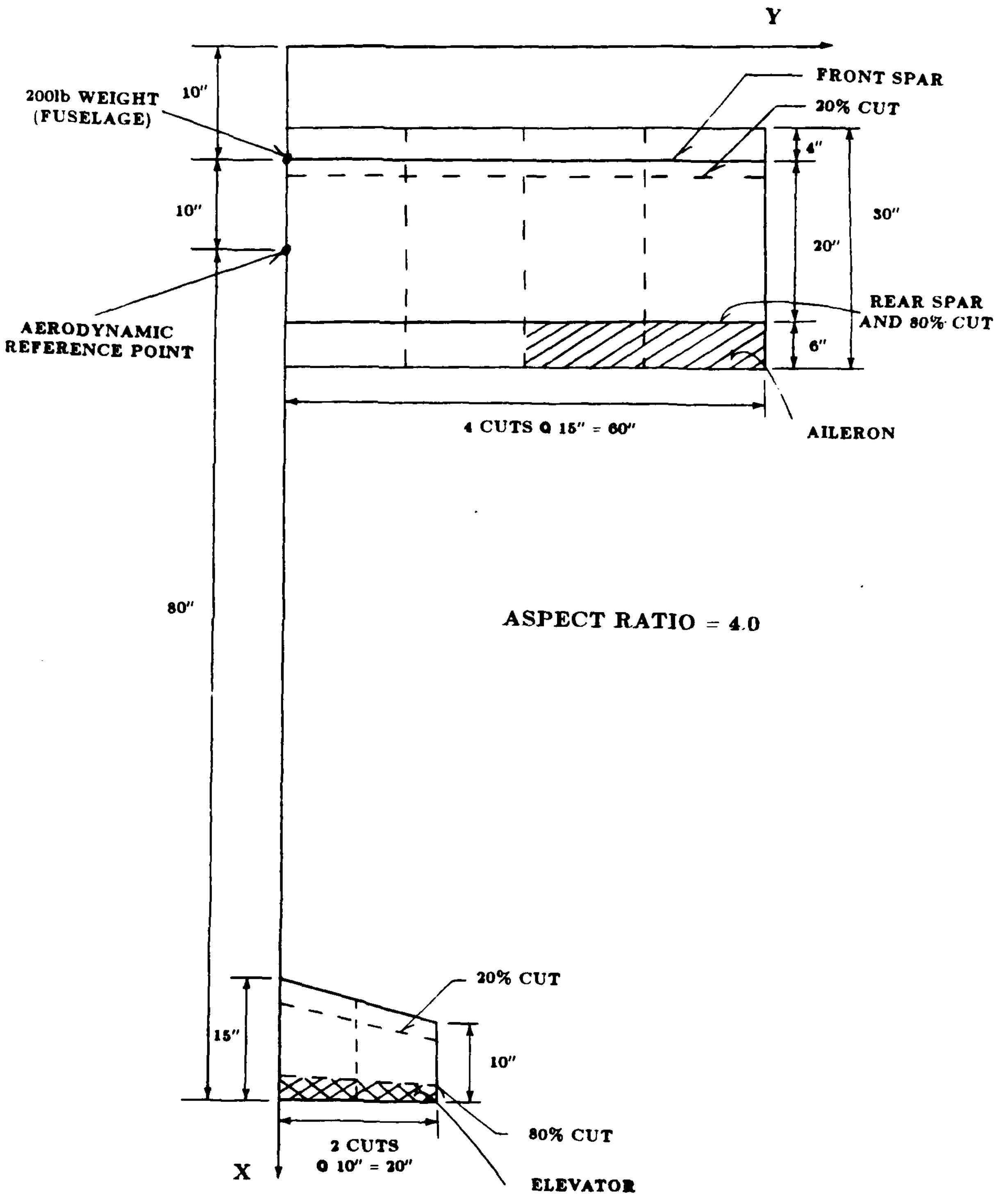


Figure 2–2: Aerodynamic Planform for Rectangular Wing

Chord station	Half thickness
0.	0.
10.	1.667
25.	1.667
50.	1.667
80.	1.667
100.	0.

Table 2–3: Airfoil Shape (all units in % chord)

Steady Aerodynamic Panel Model—Tail

The trailing edge of the elevator in figure 1 is 80" from the aerodynamic reference point (center spar). It's root chord is 15", its tip chord is 10", and its semi-span is 20". The aerodynamic box pattern for the horizontal tail shown in Figure 2–2 (3 equal spanwise cuts, and 4 chordwise cuts at 0%, 20%, 80%, and 100% of the chord). The thickness distribution is the same as for the wing as given in Table 2 with a leading edge radius of 1% An elevator is defined by the two trailing edge boxes on the tail.

2–6) For the wing-tail combination find the trimmed angle of attack, elevator deflection, and tip displacement for a symmetric **8g** pull-up maneuver defined by the flight condition in Table 2–4. Trim the aircraft for lift and pitching moment. Support the structural model for pitch and plunge rigid body modes.

Mach number	0.8
Dynamic Pressure	6.5 psi
Pitch Rate	15.7 deg/sec
Velocity	487.4 knots

Table 2–4: Flight Condition

2–7) Find the rigid and flexible stability derivatives for an anti-symmetric roll maneuver using the flight condition in Table 2–4.

For the following problems optimize the structure using the design variables for problem 2–2. For the final design in problems 2–8 through 2–10 find the values of constraints not imposed during that optimization. Which constraint(s) are critical in driving the design?

2–8) Optimize the structure for the symmetric 8g pull-up of problem 2–6. Impose stress constraints (Table 2–1) on the skins and a maximum tip rotation of 1 degree. Subtract the rotation of the support point from the relative rotation of the tip to calculate the pure elastic twist of the tip.

2–9) Repeat problem 2–8 with the addition of maximum lift effectiveness of 1.60.

2–10) Repeat problem 2–9 with the addition of a minimum aileron effectiveness of 0.30 for the anti-symmetric roll maneuver of problem 2–7.

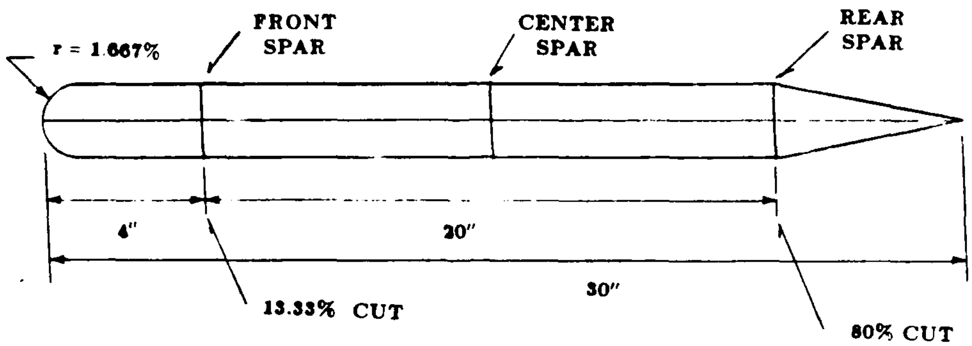


Figure 2–3: Wing Airfoil Section

ASTROS User Training Workshop
Problem Set #3: Cantilevered Plate

Structural Plate Model

The cantilevered aluminum plate in Figure 3–1 is a parallelogram (constant chord, no taper) swept 15° with a uniform thickness of 0.041". The tip is 5.52" from the cantilevered root and the unswept width (chord) is 2". The material properties are given in Table 3–1. The finite element model consists of a course 3x5 mesh.

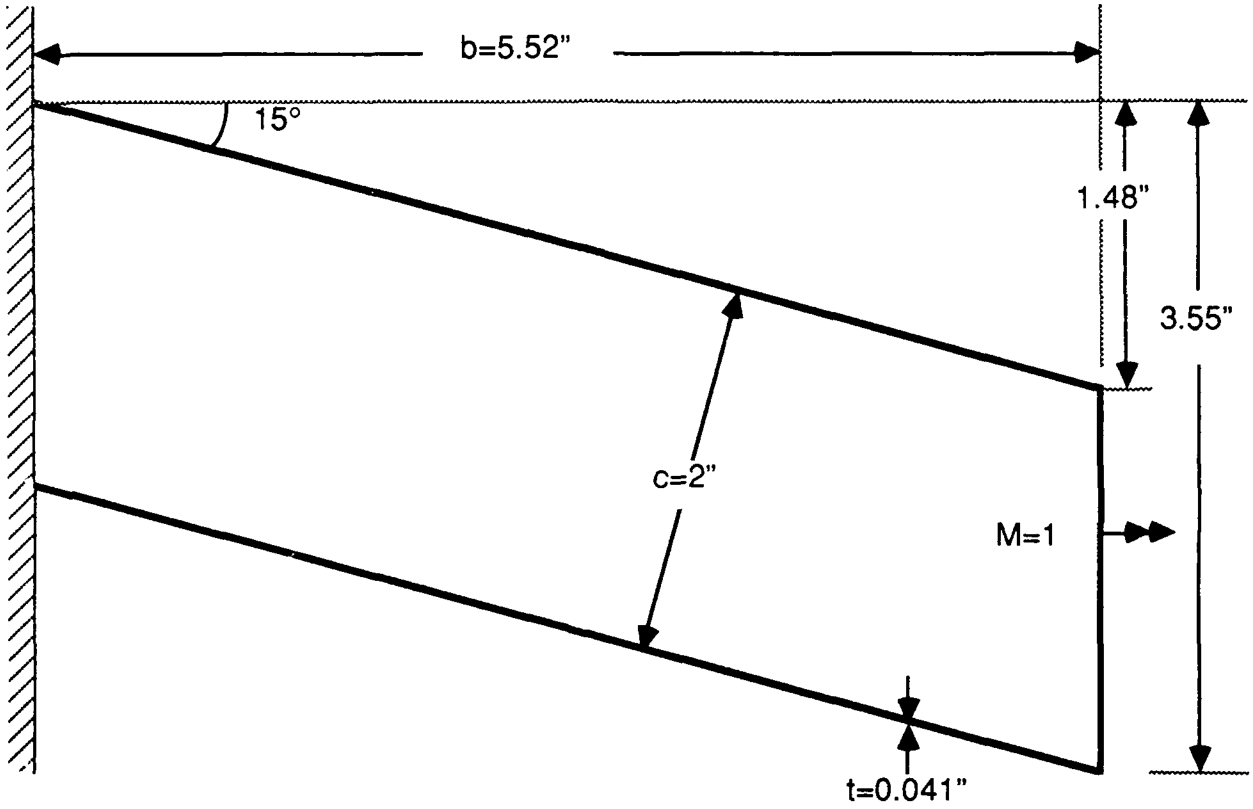


Figure 3–1: Cantilivered Plate

Young's Modulus	10.0×10^6 psi
Poisson's Ratio	0.33
Mass Density	2.59×10^{-4} lb-sec^2/in^4

Table 1—Material Properties for Magnesium

3–1) Perform a static analysis to determine the <u>displacements</u> for a unit moment applied at the one-third chord location of the tip. Next find the first three natural modes.

3–2) Determine the transient response in the time domain for the time-dependent load given in Figure 3–2 applied at the two free corners of the plate in the transverse direction.

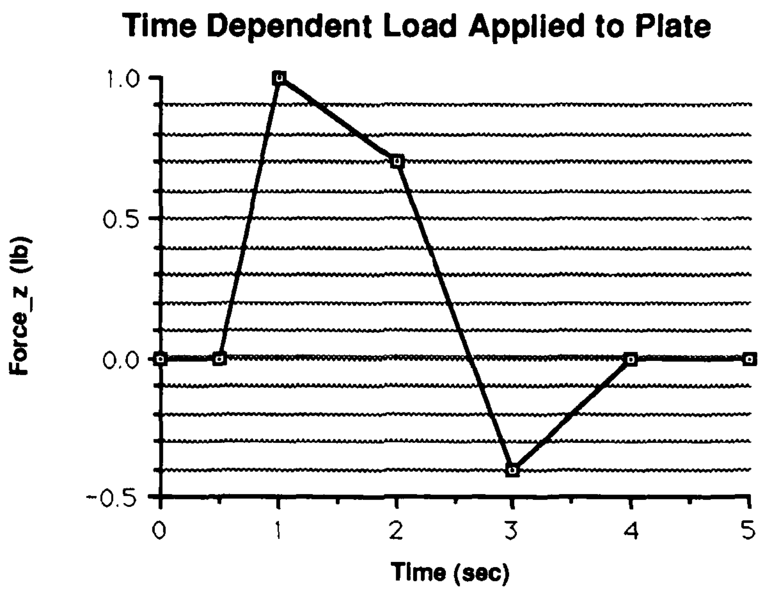


Figure 3–2: Time Dependent Load for Cantilvered Plate

Unsteady Aerodynamic Model

An unsteady aerodyanmic model consists of 5 spanwise and 10 chordwise aerodynamic boxes, equally distributed over the planform defined by Figure 3–1.

3–3) Determine the flutter speed for the subsonic and supersonic flight conditions defined in Table 3–2.

Mach number	0.45	3.0
Air Density Ratio	0.9676	0.3913
Reference Density	11.46 x 10^{-6} lb-sec^2/in^4	11.46 x 10^{-6} lb-sec^2/in^4

Table 3–2—Flight Condition

ASTROS User Training Workshop

Problem Set #4: Swept Wing

Structural Wing Box Model

The planform for a swept wing in Figure 4–1 shows the top skin of a structural model. The structural model divides the structural box into six equally spaced spanwise bays and two equal chordwise segments. The skins on both the upper and lower surface are modeled as isoparametric quadrilateral membrane elements. The ribs and spars are modeled using shear panels with rod elements for the spar caps. Rod elements are also used as posts connecting all upper and lower surface nodes. This results in 57 rod elements, 24 quadrilateral membrane elements, and 32 shear panels. The material properties are given in Table 4–1, cross-sectional properties in Table 4–2. The six nodes at the wing root are fixed (cantilvered).

4–1) Perform a statics analysis for a **4g** vertical gravity load and find the displacements and stresses.

4–2) Perform a modal analysis to determine the first five normal modes of the structure..

Design Model

The design model consists the sizes of the skins, spar webs, spar caps, and wing ribs. Use design variable linking to couple elements in each of three spanwise segments of the structure (12 design variables).

4–3) Optimize the structural box (excluding posts) subject to stress constraints on the wing skins (24 constraints) for the 4g gravity load and a 1.5 *hz* lower bound frequency constraint on the first bending mode.

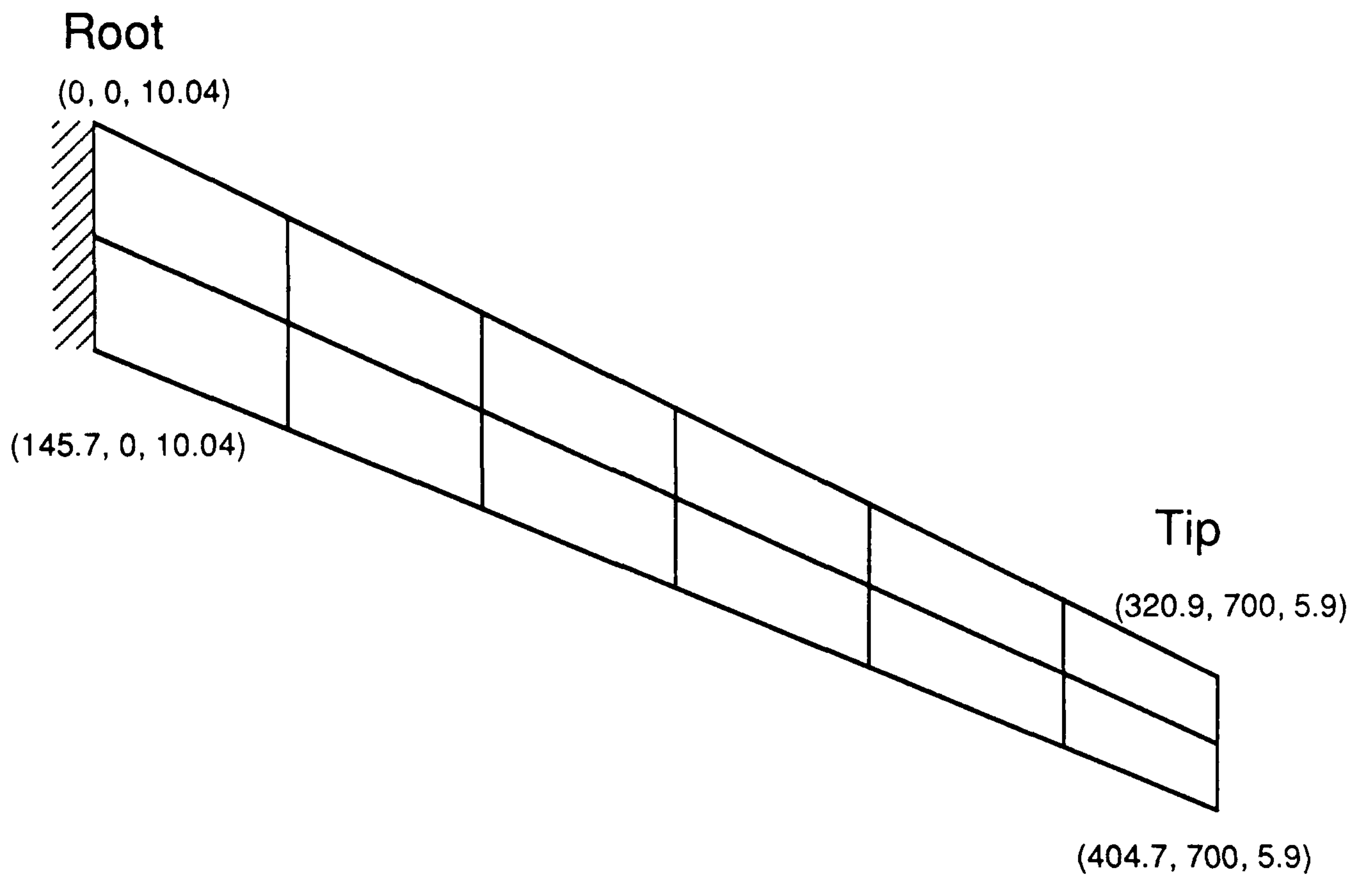


Figure 4–1—Top Surface for Swept Wing

Young's Modulus	10.0×10^6 psi
Poisson's Ratio	0.3
Weight Density	0.1 lb/in^3
Tensile Strength	60.0 ksi
Compressive Strength	50.0 ksi
Shear Strength	30.0 ksi

Table 4–1: Material Properties for Aluminum

Skin Thicknesses	0.16 in
Rib Shear Thicknesses	0.16 in
Spar Shear Thicknesses	0.32 in
Post Rod Areas	0.3 in^2
Spar Cap Rod Areas	2.0 in^2

Table 4–2: Cross-Sectional Properties

Aerodynamic Models

The planform for aerodynamic and structural models are shown together in Figure 4–2. Both the steady and unsteady aerodynamic models represent the wing as a flat plate with 50 boxes per surface. The unsteady model has ten equally spaced spanwise boxes and five chordwise boxes, while the steady model has its chordwise boxes spaced in a cosine distribution (x_i = C[1-cos(ip/5)]/2). The steady model has a horizontal stabilizer to enable trim for both lift and pitching moment. Like the wing, the tail is represented as a flat plate with ten equally spaced spanwise boxes and five chordwise boxes distributed using a cosine distribution. The last two boxes in each chordwise strip are used to represent an elevator. No structure is associated with this tail panel. Both aerodynamic wing models transfer the forces to the structural nodes on the upper surface of the structural box with a linear surface spline. The tail forces for the steady aerodynamic model are rigidly transferred to the center root of the structural box.

4–4) For flight condition 1 in Table 4–3 (Mach 0.8 at sea level) and the strucutral design point given in Table 4–2 determine whether the wing <u>flutters</u>.

4–5) For flight condition 2 in Table 4–3 (Mach 1.25 at 25,000 feet), find the <u>trimmed angle of attack</u> and <u>elevator deflection</u> for a symmetric **4g** pull-up maneuver.

Flight Condition	1 (unsteady)	2 (steady)
Mach number	0.8	1.25
Load Factor	1.0g	4.0g
Elevation	0. ft	25.0 x 10^3 ft
Air Density Ratio	1.0	0.4486
Dynamic Pressure		5.959 psi
Velocity	530.0 knots	752.6 knots
Pitch Rate		4.354°/sec

Table 4–3: Flight Conditions

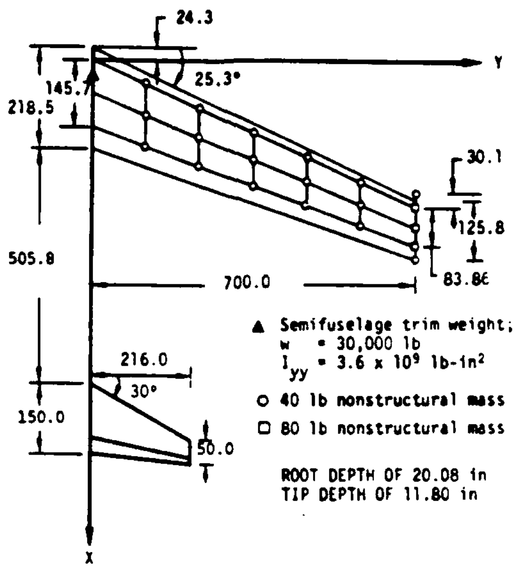


Figure 4–2: Model Geometry for Swept Wing

ASTROS User Training Workshop
Problem Set #5: Forty Member Plane Frame Optimization

The forty member plane frame shown in Figure 5–1 is subjected to the three independent loading conditions described below:

Loading condition 1:

Distributed vertical load (y direction) of 2.4 kips/ft on the intermediate levels and 1.4 kips/ft at the top level. These distributed loads are approximated by nodal forces (25% of the distributed loads at the end points and 50% at the mid span).

Loading condition 2:

Horizontal forces from the left as shown in figure 5-1 (solid arrows) plus 75% of loading condition 1.

Loading condition 3:

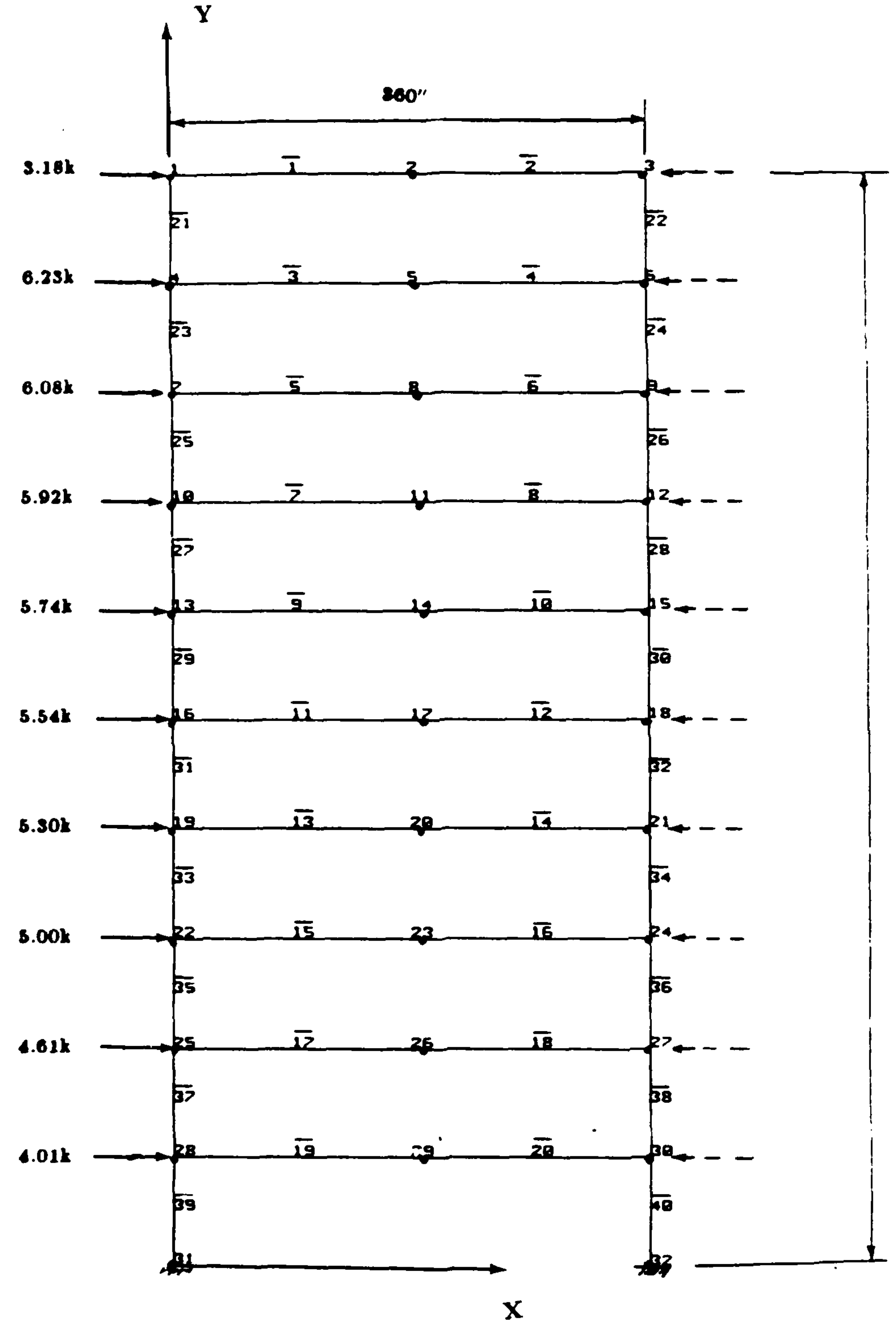
Horizontal forces from the left as shown in figure 5-1 (dashed arrows) plus 75% of loading condition 1.

Using design variable linking define 20 design variables in which the two horizontal beams at each level are grouped into one variable and similarly the the two vertical members at each level are grouped into one variable. The material properties and the intial design variables are given in Table 5–1.

Design Problem: Optimize the structure for minimum weight subjected to horizontal displacement constraints of +2" and -2 inches at the top level of the structure. The relation between the cross-sectional areas and the moment of inertia are given by $I = 4.62\ A^2$. Initial cross-sectional areas for all bars are 30 in^2. Due to symmetry of the frame there are only two independent loading conditions in view of the design variable linking.

Young's Modulus	29.0×10^6 psi
Poisson's Ratio	0.3
Weight Density	0.283 lb/in^3

Table 5–1: Material Properties for Steel



Element denoted by $\bar{i}$
Node denotee by **i**

Figure 5-1: Forty Member Plane Frame

Attachment 1

Space Truss Finite Element Bulk Data

```
$
$ Modified ACOSS II Finite Element Bulk Data
$
$ Coordinates
$
SPC1, 18, 123, 3, 4, 6
GRDSET,,,,,,,456
GRID           1        -275.591   0.000   0.000
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GRID           3        -157.480-196.850   0.000
GRID           4           0.000 196.850   0.000
GRID           5         157.480 196.850   0.000
GRID           6         157.480-196.850   0.000
GRID           7         275.591   0.000   0.000
GRID           8        -275.591   0.000  78.740
GRID           9        -157.480 196.850  78.740
GRID          10        -157.480-196.850  78.740
GRID          11         157.480 196.850  78.740
GRID          12         157.480-196.850  78.740
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GRID          15        -157.480 157.480 472.441
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GRID          24         157.480-118.110 866.142
GRID          25         196.850   0.000 866.142
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GRID          33         157.480-118.110 944.882
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CROD           3   10001       2       3
CROD           4   10001       2       4
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CROD           6   10001       4       5
CROD           7   10001       4       6
CROD           8   10001       3       6
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CROD          11   10001       6       7
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```

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CROD	18	10001	3	8
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CROD	70	10001	17	27

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CROD           113   10001      25       32
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+MT     1 3.00E+4 3.00E+4
$
$ Non-structural masses.
$
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CONM2, 10, 10, , 2.855
CONM2, 11, 11, , 2.855
CONM2, 12, 12, , 2.855
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CONM2, 15, 15, , 0.097
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CONM2, 28, 28, , 1.428
CONM2, 29, 29, , 1.428
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Attachment 2

Rectangular Wing Finite Element Bulk Data

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$ Coordinates for Rectangular Wing Box (inches)
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GRID           6        30.0    60.0     -0.50
GRID           7        10.0    30.0      0.50
GRID           8        10.0    30.0     -0.50
GRID           9        20.0    30.0      0.50
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GRID          16        20.0    0.0      -0.50
GRID          17        30.0    0.0       0.50
GRID          18        30.0    0.0      -0.50
$ Aerodynamic Reference Point
GRID          20        20.0    0.0      0.0                      126
$
$ Rigid Connection to Fuselage
$
$ Root connection chordwise
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MPC, 100, 14, 1, -1.0, 20, 1, 1.0, , , 20, 5, -0.5
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MPC, 100, 16, 1, -1.0, 20, 1, 1.0, , , 20, 5, -0.5
MPC, 100, 17, 1, -1.0, 20, 1, 1.0, , , 20, 5,  0.5
MPC, 100, 18, 1, -1.0, 20, 1, 1.0, , , 20, 5, -0.5
$ Root connection spanwise
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MPC, 100, 15, 2, -1.0, 20, 2, 1.0, , , 20, 4, -0.5
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$ Root connection veritically
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$
$ Top Skins
$
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CQDMEM1    10002    10001        3        5       11        9   0.0
CQDMEM1    10003    10002        7        9       15       13   0.0
CQDMEM1    10004    10002        9       11       17       15   0.0
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PQDMEM1    10002        2  0.2000
$
$ Bottom Skins
$
CQDMEM1    20001   20001        2        4       10        8  0.0
CQDMEM1    20002   20001        4        6       12       10  0.0
CQDMEM1    20003   20002        8       10       16       14  0.0
CQDMEM1    20004   20002       10       12       18       16  0.0
PQDMEM1    20001        2  0.2000
PQDMEM1    20002        2  0.2000
$
$ Spars
$
CSHEAR     30001   30001        1        2        8        7
CSHEAR     30002   30001        3        4       10        9
CSHEAR     30003   30001        5        6       12       11
CSHEAR     30004   30001        7        8       14       13
CSHEAR     30005   30001        9       10       16       15
CSHEAR     30006   30001       11       12       18       17
PSHEAR     30001        1  0.0500  0.0
$
$ Ribs
$
CSHEAR     40001   40001        1        3        4        2
CSHEAR     40002   40001        3        5        6        4
CSHEAR     40003   40001        7        9       10        8
CSHEAR     40004   40001        9       11       12       10
CSHEAR     40005   40001       13       15       16       14
CSHEAR     40006   40001       15       17       18       16
PSHEAR     40001        1  0.0500  0.0
$
$ Posts
$
CROD       50001   50001        1        2
CROD       50002   50001        3        4
CROD       50003   50001        5        6
CROD       50004   50001        7        8
CROD       50005   50001        9       10
CROD       50006   50001       11       12
CROD       50007   50001       13       14
CROD       50008   50001       15       16
CROD       50009   50001       17       18
PROD       50001        1    0.01     0.00    0.000    0.000
$
$ Materials
$
MAT1             1 10.0E+6          0.30     0.10
+MT1
+MT1      20.0E+3 15.0E+3 12.0E+3
MAT1             2 10.0E+6          0.30     0.10
+MT2
+MT2      20.0E+3 15.0E+3 12.0E+3
$
$ Fuselage Mass
$
CONM2, 1, 20, , 200.0, -10.0, 0.0, 0.0, , +CONM
+CONM, , , 22500., , , 22500.
```

```
$
$ Weight to Mass Conversion (for densities and lumped masses)
$
CONVERT, MASS, 0.00259
```

Attachment 3
Cantilevered Plate Finite Element Bulk Data

```
$
$     15 DEGREE SWEPT, UNTAPERED WING. (SEE NACA RM L55E11 FOR A
$     DESCRIPTION OF THE MODEL)  THE STRUCTURE IS MODELLED USING
$     15 CQUAD4 ELEMENTS IN A 3 X 15 ELEMENT GRID.  24 GRID POINTS
$     ARE REQUIRED TO DEFINE THE CORNERS OF THE BENDING ELEMENTS.
$
$     M=.45  EXPERIMENTAL RESULTS:     FLUTTER VEL = 495 FPS (5940
IN/SEC)
$                                      FLUTTER FREQ = 120 HZ
$
GRID           1          0.000   0.000   0.000          123456
GRID           2          0.690   0.000   0.000          123456
GRID           3          1.380   0.000   0.000          123456
GRID           4          2.070   0.000   0.000          123456
$
GRID           5          0.296   1.104   0.000
GRID           6          0.986   1.104   0.000
GRID           7          1.676   1.104   0.000
GRID           8          2.366   1.104   0.000
$
GRID           9          0.592   2.208   0.000
GRID          10          1.282   2.208   0.000
GRID          11          1.972   2.208   0.000
GRID          12          2.662   2.208   0.000
$
GRID          13          0.888   3.312   0.000
GRID          14          1.578   3.312   0.000
GRID          15          2.268   3.312   0.000
GRID          16          2.958   3.312   0.000
$
GRID          17          1.184   4.416   0.000
GRID          18          1.874   4.416   0.000
GRID          19          2.564   4.416   0.000
GRID          20          3.254   4.416   0.000
$
GRID          21          1.480   5.520   0.000
GRID          22          2.170   5.520   0.000
GRID          23          2.860   5.520   0.000
GRID          24          3.550   5.520   0.000
$
CQUAD4       101     100       1       2       6       5
CQUAD4       102     100       2       3       7       6
CQUAD4       103     100       3       4       8       7
CQUAD4       104     100       5       6      10       9
CQUAD4       105     100       6       7      11      10
CQUAD4       106     100       7       8      12      11
CQUAD4       107     100       9      10      14      13
CQUAD4       108     100      10      11      15      14
CQUAD4       109     100      11      12      16      15
CQUAD4       110     100      13      14      18      17
CQUAD4       111     100      14      15      19      18
CQUAD4       112     100      15      16      20      19
CQUAD4       113     100      17      18      22      21
CQUAD4       114     100      18      19      23      22
CQUAD4       115     100      19      20      24      23
```

Attachment 4
Swept Wing Finite Element Bulk Data

```
$
$       SWEPT WING MODEL FROM
$       "A ROOT LOCUS BASED FLUTTER SYNTHESIS PROCEDURE" BY
$       P. HAJELA   STANFORD U.
$       WITH A FLUTTER CONSTRAINT AT SEA LEVEL FOR M=0.80
$       STRESS CONSTRAINTS UNDER A 4 G STATIC AIR LOAD AT
$       25000 FT. (M = 1.25) AND A 1.5 HZ LOW. BOUND FREQ. CONSTRNT.
$
GRID           1             0.0     0.0  10.039
GRID           2             0.0     0.0 -10.039
GRID           3         72.8345     0.0  10.039
GRID           4         72.8345     0.0 -10.039
GRID           5        145.6690     0.0  10.039
GRID           6        145.6690     0.0 -10.039
GRID           7         53.4758 116.667  9.3502
GRID           8         53.4758 116.667 -9.3502
GRID           9        121.1590 116.667  9.3502
GRID          10        121.1590 116.667 -9.3502
GRID          11        188.8430 116.667  9.3502
GRID          12        188.8430 116.667 -9.3502
GRID          13        106.9520 233.333  8.6613
GRID          14        106.9520 233.333 -8.6613
GRID          15        169.4840 233.333  8.6613
GRID          16        169.4840 233.333 -8.6613
GRID          17        232.0170 233.333  8.6613
GRID          18        232.0170 233.333 -8.6613
GRID          19        160.4280 350.0    7.9724
GRID          20        160.4280 350.0   -7.9724
GRID          21        217.8090 350.0    7.9724
GRID          22        217.8090 350.0   -7.9724
GRID          23        275.1910 350.0    7.9724
GRID          24        275.1910 350.0   -7.9724
GRID          25        213.9030 466.667  7.2834
GRID          26        213.9030 466.667 -7.2834
GRID          27        266.1340 466.667  7.2834
GRID          28        266.1340 466.667 -7.2834
GRID          29        318.3650 466.667  7.2834
GRID          30        318.3650 466.667 -7.2834
GRID          31        267.3780 583.333  6.5945
GRID          32        267.3780 583.333 -6.5945
GRID          33        314.4590 583.333  6.5945
GRID          34        314.4590 583.333 -6.5945
GRID          35        361.5390 583.333  6.5945
GRID          36        361.5390 583.333 -6.5945
GRID          37        320.8550 700.0    5.9055
GRID          38        320.8550 700.0   -5.9055
GRID          39        362.7840 700.0    5.9055
GRID          40        362.7840 700.0   -5.9055
GRID          41        404.7130 700.0    5.9055
GRID          42        404.7130 700.0   -5.9055
GRID          43        290.7840 700.0       0.0
GRID          44        434.7830 700.0       0.0
GRID          45        72.8345  0.0         0.0
$
```

```
$       BOUNDARY CONDITION 1
$
MPC,    101,     43,    1,    -4.0,    37,     1,   1.0, , MPC4311
+PC4311,  ,      38,    1,     1.0,    39,     1,   1.0, , MPC4312
+PC4312,  ,      40,    1,     1.0
MPC,    101,     44,    1,    -4.0,    39,     1,   1.0, , MPC4411
+PC4411,  ,      40,    1,     1.0,    41,     1,   1.0, , MPC4412
+PC4412,  ,      42,    1,     1.0
MPC,    101,     43,    2,    -4.0,    37,     2,   1.0, , MPC4321
+PC4321,  ,      38,    2,     1.0,    39,     2,   1.0, , MPC4322
+PC4322,  ,      40,    2,     1.0
MPC,    101,     44,    2,    -4.0,    39,     2,   1.0, , MPC4421
+PC4421,  ,      40,    2,     1.0,    41,     2,   1.0, , MPC4422
+PC4422,  ,      42,    2,     1.0
MPC,    101,     43,    3,       -1.0,    37,     3, 0.85859, , MPC4331
+PC4331,  ,      38,    3,    0.85859,    39,     3,-0.35859, , MPC4332
+PC4332,  ,      40,    3,   -0.35859
MPC,    101,     44,    3,       -1.0,    39,     3,-0.35859, , MPC4431
+PC4431,  ,      40,    3,   -0.35859,    41,     3, 0.85859, , MPC4432
+PC4432,  ,      42,    3,    0.85859
SPC1,       10,  123456,     1,    THRU,     6,    45
SPC1,       10,     456,     7,    THRU,    44
ASET1,  100,  3,   7,   9, 11, 13, 15, 17, ASETA
+SETA,    19, 21, 23, 25, 27, 29, 31, 33, ASETB
+SETB,    35, 37, 39, 41
$
$        BOUNDARY CONDITION 2
$
MPCADD,   2101,    101,    201
MPC,    201,     3,   1,       1.0,   45,    5,  -10.04
MPC,    201,     3,   3,       1.0,   45,    3,  -1.0
MPC,    201,     4,   1,       1.0,   45,    5,  10.04
MPC,    201,     4,   3,       1.0,   45,    3,  -1.0
SPC1,  110,     1246,      45
SPC1,  110,  2456,         1,     THRU,       6
SPC1,  110,   456,         7,     THRU,      44
ASET1,  1100,  3,  7,   9, 11, 13, 15, 17, ASETA
+SETA,    19, 21, 23, 25, 27, 29, 31, 33, ASETB
+SETB,    35, 37, 39, 41, 45, 1, 5
ASET1, 1100, 5, 45
SUPORT,  1,       45,     35
$
$        UPPER AND LOWER SKINS 100 - UPPER, 200 - LOWER
$
CQDMEM1       101     1004        1        7       9       3
CQDMEM1       201     1004        2        8      10       4
CQDMEM1       102     1004        3        9      11       5
CQDMEM1       202     1004        4       10      12       6
CQDMEM1       103     1004        7       13      15       9
CQDMEM1       203     1004        8       14      16      10
CQDMEM1       104     1004        9       15      17      11
CQDMEM1       204     1004       10       16      18      12
CQDMEM1       105     1005       13       19      21      15
CQDMEM1       205     1005       14       20      22      16
CQDMEM1       106     1005       15       21      23      17
CQDMEM1       206     1005       16       22      24      18
CQDMEM1       107     1005       19       25      27      21
CQDMEM1       207     1005       20       26      28      22
```

```
CQDMEM1     108    1005      21      27      29      23
CQDMEM1     208    1005      22      28      30      24
CQDMEM1     109    1006      25      31      33      27
CQDMEM1     209    1006      26      32      34      28
CQDMEM1     110    1006      27      33      35      29
CQDMEM1     210    1006      28      34      36      30
CQDMEM1     111    1006      31      37      39      33
CQDMEM1     211    1006      32      38      40      34
CQDMEM1     112    1006      33      39      41      35
CQDMEM1     212    1006      34      40      42      36
$
$       MODEL SUB STRUCTURE
$       SHEAR PANELS:  300 - LE,   350 - MID, 400 - TE, 500 - CHORDWISE
$       AXIAL RODS:  600 - INBOARD  2 BAYS
$                    700 - MID SPAN 2 BAYS
$                    800 - OUTBOARD 2 BAYS
$
CSHEAR      301    2007       1       2       8       7
CSHEAR      351    2007       3       4      10       9
CSHEAR      401    2007       5       6      12      11
CSHEAR      302    2007       7       8      14      13
CSHEAR      352    2007       9      10      16      15
CSHEAR      402    2007      11      12      18      17
CSHEAR      303    2008      13      14      20      19
CSHEAR      353    2008      15      16      22      21
CSHEAR      403    2008      17      18      24      23
CSHEAR      304    2008      19      20      26      25
CSHEAR      354    2008      21      22      28      27
CSHEAR      404    2008      23      24      30      29
CSHEAR      305    2009      25      26      32      31
CSHEAR      355    2009      27      28      34      33
CSHEAR      405    2009      29      30      36      35
CSHEAR      306    2009      31      32      38      37
CSHEAR      356    2009      33      34      40      39
CSHEAR      406    2009      35      36      42      41
CSHEAR      501    2010       7       8      10       9
CSHEAR      502    2010       9      10      12      11
CSHEAR      503    2010      13      14      16      15
CSHEAR      504    2010      15      16      18      17
CSHEAR      505    2011      19      20      22      21
CSHEAR      506    2011      21      22      24      23
CSHEAR      507    2011      25      26      28      27
CSHEAR      508    2011      27      28      30      29
CSHEAR      509    2012      31      32      34      33
CSHEAR      510    2012      33      34      36      35
CSHEAR      511    2012      37      38      40      39
CSHEAR      512    2012      39      40      42      41
CSHEAR      513    2010       1       2       4       3
CSHEAR      514    2010       3       4       6       5
$
CONROD     1201       1       2      90     0.3
CONROD     1202       3       4      90     0.3
CONROD     1203       5       6      90     0.3
CONROD     1301       7       8      90     0.3
CONROD     1302      13      14      90     0.3
CONROD     1303      19      20      90     0.3
CONROD     1304      25      26      90     0.3
CONROD     1305      31      32      90     0.3
```

```
CONROD  1306    37      38      90      0.3
CONROD  1401    9       10      90      0.3
CONROD  1402    15      16      90      0.3
CONROD  1403    21      22      90      0.3
CONROD  1404    27      28      90      0.3
CONROD  1405    33      34      90      0.3
CONROD  1406    39      40      90      0.3
CONROD  1501    11      12      90      0.3
CONROD  1502    17      18      90      0.3
CONROD  1503    23      24      90      0.3
CONROD  1504    29      30      90      0.3
CONROD  1505    35      36      90      0.3
CONROD  1506    41      42      90      0.3
CROD    601     6001    1       7
CROD    602     6001    2       8
CROD    603     6001    3       9
CROD    604     6001    4       10
CROD    605     6001    5       11
CROD    606     6001    6       12
CROD    607     6001    7       13
CROD    608     6001    8       14
CROD    609     6001    9       15
CROD    610     6001    10      16
CROD    611     6001    11      17
CROD    612     6001    12      18
CROD    701     7002    13      19
CROD    702     7002    14      20
CROD    703     7002    15      21
CROD    704     7002    16      22
CROD    705     7002    17      23
CROD    706     7002    18      24
CROD    707     7002    19      25
CROD    708     7002    20      26
CROD    709     7002    21      27
CROD    710     7002    22      28
CROD    711     7002    23      29
CROD    712     7002    24      30
CROD    801     8003    25      31
CROD    802     8003    26      32
CROD    803     8003    27      33
CROD    804     8003    28      34
CROD    805     8003    29      35
CROD    806     8003    30      36
CROD    807     8003    31      37
CROD    808     8003    32      38
CROD    809     8003    33      39
CROD    810     8003    34      40
CROD    811     8003    35      41
CROD    812     8003    36      42
$
CONM2   50001   7               20.0
CONM2   50002   8               20.0
CONM2   50003   9               20.0
CONM2   50004   10              20.0
CONM2   50005   11              20.0
CONM2   50006   12              20.0
CONM2   50007   13              20.0
CONM2   50008   14              20.0
```

```
CONM2       50009       15              20.0
CONM2       50010       16              20.0
CONM2       50011       17              20.0
CONM2       50012       18              20.0
CONM2       50013       19              20.0
CONM2       50014       20              20.0
CONM2       50015       21              20.0
CONM2       50016       22              20.0
CONM2       50017       23              20.0
CONM2       50018       24              20.0
CONM2       50019       25              20.0
CONM2       50020       26              20.0
CONM2       50021       27              20.0
CONM2       50022       28              20.0
CONM2       50023       29              20.0
CONM2       50024       30              20.0
CONM2       50025       31              20.0
CONM2       50026       32              20.0
CONM2       50027       33              20.0
CONM2       50028       34              20.0
CONM2       50029       35              20.0
CONM2       50030       36              20.0
CONM2       50031       37              40.0
CONM2       50032       38              40.0
CONM2       50033       39              40.0
CONM2       50034       40              40.0
CONM2       50035       41              40.0
CONM2       50036       42              40.0
CONM2       50037       43              40.0
CONM2       50038       44              40.0
$
$       TRIM WEIGHT AT ROOT 1/4 CHORD INCLUDING ROTATIONAL INERTIA
$
CONM2,      51001,      45, , 30000.0, -36.0, , , , +CM01
+CM01,              ,         , 3.6E9
$
PQDMEM1,  1004,    91,     0.04
PQDMEM1,  1005,    91,     0.04
PQDMEM1,  1006,    91,     0.04
$
PSHEAR,   2007,    90,     0.04
PSHEAR,   2008,    90,     0.04
PSHEAR,   2009,    90,     0.04
PSHEAR,   2010,    90,     0.04
PSHEAR,   2011,    90,     0.04
PSHEAR,   2012,    90,     0.04
$
PROD,     6001,    90,     1.0
PROD,     7002,    90,     1.0
PROD,     8003,    90,     1.0
$
$ Material properties
$
MAT1,        90,      10.E6,    ,    0.3,     0.1
MAT1,        91,      10.E6,    ,    0.3,     0.1, , , , ABC
+BC,    60000.0,    50000.0, 30000.0
$
CONVERT,  MASS,   2.588E-3
```

Attachment 5
Plane Frame Finite Element Bulk Data

```
GRDSET, , , , , , , 345
GRID, 1, ,   0.,1200., 0.
GRID, 2, , 180.,1200., 0.
GRID, 3, , 360.,1200., 0.
GRID, 4, ,   0.,1080., 0.
GRID, 5, , 180.,1080., 0.
GRID, 6, , 360.,1080., 0.
GRID, 7, ,   0.,960., 0.
GRID, 8, , 180.,960., 0.
GRID, 9, , 360.,960., 0.
GRID,10, ,   0.,840., 0.
GRID,11, , 180.,840., 0.
GRID,12, , 360.,840., 0.
GRID,13, ,   0.,720., 0.
GRID,14, , 180.,720., 0.
GRID,15, , 360.,720., 0.
GRID,16, ,   0.,600., 0.
GRID,17, , 180.,600., 0.
GRID,18, , 360.,600., 0.
GRID,19, ,   0.,480., 0.
GRID,20, , 180.,480., 0.
GRID,21, , 360.,480., 0.
GRID,22, ,   0.,360., 0.
GRID,23, , 180.,360., 0.
GRID,24, , 360.,360., 0.
GRID,25, ,   0.,240., 0.
GRID,26, , 180.,240., 0.
GRID,27, , 360.,240., 0.
GRID,28, ,   0.,120., 0.
GRID,29, , 180.,120., 0.
GRID,30, , 360.,120., 0.
GRID,31, ,   0.,  0., 0.
GRID,32, , 360.,  0., 0.
BAROR, , , , , 0., 0., 1.
CBAR, 1, 1, 1, 2, , , ,1000.
CBAR, 2, 1, 2, 3, , , ,1000.
CBAR, 3, 1, 4, 5, , , ,1000.
CBAR, 4, 1, 5, 6, , , ,1000.
CBAR, 5, 1, 7, 8, , , ,1000.
CBAR, 6, 1, 8, 9, , , ,1000.
CBAR, 7, 1, 10, 11, , , ,1000.
CBAR, 8, 1, 11, 12, , , ,1000.
CBAR, 9, 1, 13, 14, , , ,1000.
CBAR,10, 1, 14, 15, , , ,1000.
CBAR,11, 1, 16, 17, , , ,1000.
CBAR,12, 1, 17, 18, , , ,1000.
CBAR,13, 1, 19, 20, , , ,1000.
CBAR,14, 1, 20, 21, , , ,1000.
CBAR,15, 1, 22, 23, , , ,1000.
CBAR,16, 1, 23, 24, , , ,1000.
CBAR,17, 1, 25, 26, , , ,1000.
CBAR,18, 1, 26, 27, , , ,1000.
CBAR,19, 1, 28, 29, , , ,1000.
CBAR,20, 1, 29, 30, , , ,1000.
CBAR,21, 1, 1,  4, , , ,1000.
```

```
CBAR,22, 1, 3,  6, , , ,1000.
CBAR,23, 1, 4,  7, , , ,1000.
CBAR,24, 1, 6,  9, , , ,1000.
CBAR,25, 1, 7, 10, , , ,1000.
CBAR,26, 1, 9, 12, , , ,1000.
CBAR,27, 1, 10, 13, , , ,1000.
CBAR,28, 1, 12, 15, , , ,1000.
CBAR,29, 1, 13, 16, , , ,1000.
CBAR,30, 1, 15, 18, , , ,1000.
CBAR,31, 1, 16, 19, , , ,1000.
CBAR,32, 1, 18, 21, , , ,1000.
CBAR,33, 1, 19, 22, , , ,1000.
CBAR,34, 1, 21, 24, , , ,1000.
CBAR,35, 1, 22, 25, , , ,1000.
CBAR,36, 1, 24, 27, , , ,1000.
CBAR,37, 1, 25, 28, , , ,1000.
CBAR,38, 1, 27, 30, , , ,1000.
CBAR,39, 1, 28, 31, , , ,1000.
CBAR,40, 1, 30, 32, , , ,1000.
FORCE, 1, 1, , 1000.,  0.,  -6., 0.
FORCE, 1, 2, , 1000.,  0., -24., 0.
FORCE, 1, 3, , 1000.,  0.,  -6., 0.
FORCE, 1, 4, , 1000.,  0., -12., 0.
FORCE, 1, 5, , 1000.,  0., -48., 0.
FORCE, 1, 6, , 1000.,  0., -12., 0.
FORCE, 1, 7, , 1000.,  0., -12., 0.
FORCE, 1, 8, , 1000.,  0., -48., 0.
FORCE, 1, 9, , 1000.,  0., -12., 0.
FORCE, 1,10, , 1000.,  0., -12., 0.
FORCE, 1,11, , 1000.,  0., -48., 0.
FORCE, 1,12, , 1000.,  0., -12., 0.
FORCE, 1,13, , 1000.,  0., -12., 0.
FORCE, 1,14, , 1000.,  0., -48., 0.
FORCE, 1,15, , 1000.,  0., -12., 0.
FORCE, 1,16, , 1000.,  0., -12., 0.
FORCE, 1,17, , 1000.,  0., -48., 0.
FORCE, 1,18, , 1000.,  0., -12., 0.
FORCE, 1,19, , 1000.,  0., -12., 0.
FORCE, 1,20, , 1000.,  0., -48., 0.
FORCE, 1,21, , 1000.,  0., -12., 0.
FORCE, 1,22, , 1000.,  0., -12., 0.
FORCE, 1,23, , 1000.,  0., -48., 0.
FORCE, 1,24, , 1000.,  0., -12., 0.
FORCE, 1,25, , 1000.,  0., -12., 0.
FORCE, 1,26, , 1000.,  0., -48., 0.
FORCE, 1,27, , 1000.,  0., -12., 0.
FORCE, 1,28, , 1000.,  0., -12., 0.
FORCE, 1,29, , 1000.,  0., -48., 0.
FORCE, 1,30, , 1000.,  0., -12., 0.
FORCE, 2, 1, , 1000.,  0., -4.5, 0.
FORCE, 2, 2, , 1000.,  0., -18., 0.
FORCE, 2, 3, , 1000.,  0., -4.5, 0.
FORCE, 2, 4, , 1000.,  0.,  -9., 0.
FORCE, 2, 5, , 1000.,  0., -36., 0.
FORCE, 2, 6, , 1000.,  0.,  -9., 0.
FORCE, 2, 7, , 1000.,  0.,  -9., 0.
FORCE, 2, 8, , 1000.,  0., -36., 0.
FORCE, 2, 9, , 1000.,  0.,  -9., 0.
```

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FORCE, 2,10, , 1000., 0., -9., 0.
FORCE, 2,11, , 1000., 0., -36., 0.
FORCE, 2,12, , 1000., 0., -9., 0.
FORCE, 2,13, , 1000., 0., -9., 0.
FORCE, 2,14, , 1000., 0., -36., 0.
FORCE, 2,15, , 1000., 0., -9., 0.
FORCE, 2,16, , 1000., 0., -9., 0.
FORCE, 2,17, , 1000., 0., -36., 0.
FORCE, 2,18, , 1000., 0., -9., 0.
FORCE, 2,19, , 1000., 0., -9., 0.
FORCE, 2,20, , 1000., 0., -36., 0.
FORCE, 2,21, , 1000., 0., -9., 0.
FORCE, 2,22, , 1000., 0., -9., 0.
FORCE, 2,23, , 1000., 0., -36., 0.
FORCE, 2,24, , 1000., 0., -9., 0.
FORCE, 2,25, , 1000., 0., -9., 0.
FORCE, 2,26, , 1000., 0., -36., 0.
FORCE, 2,27, , 1000., 0., -9., 0.
FORCE, 2,28, , 1000., 0., -9., 0.
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FORCE, 2,30, , 1000., 0., -9., 0.
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FORCE, 2,16, , 1000., 5.54, 0., 0.
FORCE, 2,19, , 1000., 5.30, 0., 0.
FORCE, 2,22, , 1000., 5.00, 0., 0.
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FORCE, 3,22, , 1000., 0., -9., 0.
FORCE, 3,23, , 1000., 0., -36., 0.
FORCE, 3,24, , 1000., 0., -9., 0.
FORCE, 3,25, , 1000., 0., -9., 0.
FORCE, 3,26, , 1000., 0., -36., 0.
FORCE, 3,27, , 1000., 0., -9., 0.
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FORCE, 3,28, , 1000.,  0.,  -9., 0.
FORCE, 3,29, , 1000.,  0., -36., 0.
FORCE, 3,30, , 1000.,  0.,  -9., 0.
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FORCE, 3, 6, , 1000., -6.23, 0., 0.
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FORCE, 3,12, , 1000., -5.92, 0., 0.
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FORCE, 3,18, , 1000., -5.54, 0., 0.
FORCE, 3,21, , 1000., -5.30, 0., 0.
FORCE, 3,24, , 1000., -5.00, 0., 0.
FORCE, 3,27, , 1000., -4.61, 0., 0.
FORCE, 3,30, , 1000., -4.00, 0., 0.
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+MAT1, 24.+3, 24.+3, 24.+9
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